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Illinois State Water Survey Div., Champaign

Prepared for

Illinois State Environmental Protection Agency
Springfield

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This was a study conducted to determine the effectiveness of streetsweeping as a control measure for pollutants from urban areas that would otherwise end up as nonpoint pollution in the runoff from storm events. Included was street dirt sampling to measure total loads of material on the street, and particle/size distributions and constituent concentrations in the street loads. Different streetsweeping frequencies were also evaluated.

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FINAL REPORT

NATIONWIDE URBAN RUNOFF PROJECT, CHAMPAIGN, ILLINOIS: EVALUATION OF THE EFFECTIVENESS OF MUNICIPAL STREET SWEEPING IN THE CONTROL OF URBAN STORM RUNOFF POLLUTION

by

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prepared for

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ABSTRACT

In March 1982, the Illinois State Water Survey (ISWS) completed a three-year study for the Illinois Environmental Protection Agency (IEPA) to determine the effects of municipal street sweeping on urban storm runoff quality. The project was part of the Nationwide Urban Runoff Program sponsored by the U.S. Environmental Protection Agency.

In Champaign, Illinois, four urban drainage basins featuring separate sewers and ranging in size from 16 to 55 acres were instrumented for runoff event monitoring and sampling. In addition, a single inlet within one of the basins was instrumented. Data collection included recording of precipitation and storm runoff, and sampling of runoff and atmospheric fallout. A telemetry system was developed and installed to link the remote sampling sites to a small computer which automatically controlled the collection and storage of data and the instruction for sampling. During 1980 and 1981, samples were collected and analyzed for total concentrations of solids, nutrients, and metals for 90 events. A street dirt sampling program designed to measure the total loads of material on the streets was conducted over the same time span. Determinations were made of the particle size distributions and constituent concentrations in the street loads. Municipal street sweeping at different frequencies was practiced on the basins during the monitoring period.

The procedures used in data collection and the results obtained from the sampling programs are presented and discussed. For the conditions monitored, street sweeping is shown to be ineffective as a management practice for urban storm runoff quality.

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EXECUTIVE SUMMARY

The Nationwide Urban Runoff Program was designed by the United States Environmental Protection Agency to investigate three aspects of urban storm runoff across the country: type and extent of urban runoff problems, impacts of urban runoff on receiving waters, and effectiveness of recommended control practices. The Illinois Environmental Protection Agency proposed a project which was accepted to be one of 28 projects in the program. The project proposed by IEPA was an evaluation of the effectiveness of municipal street sweeping in controlling urban storm runoff quality. IEPA contracted with the Illinois State Water Survey to perform the study which started in June 1979 and ended in March 1982.

Four separately sewered urban drainage basins in Champaign, Illinois, were selected as the study sites. Two basins were entirely comprised of single-family residential land use; these had areas of 39 and 55 acres. The other basins featured multi-family residential and strip commercial land uses; their areas were 16 and 28 acres. The outlets of the storm sewer networks in all four basins were instrumented for flow monitoring and water quality sampling. In addition, four rain gages and three wet-dry fallout samplers were operated in the basins. A computer-controlled telemetry network was installed and developed for collection, storage, and management of runoff event data. During storms, rainfall and flow data from the sites were recorded at one-minute intervals. For about half the duration of the project, runoff quality was determined by analyzing discrete samples collected at five-minute intervals throughout the events; the rest of the time, flow-weighted composite samples were collected and analyzed. Laboratory determinations of concentrations of a variety of constituents, including solids, metals, and nutrients, were made on the runoff samples. In all, 90 storm events were monitored and sampled during the 1980-81 seasons. Rainfall samples for 26 of the events were kept and analyzed.

Municipal street sweeping in the basins during this study was restricted by the City of Champaign. In 1980 there was a period of five months, from early March to mid-July, in which there was no sweeping of any of the basins. Starting in late July, one residential basin and one commercial basin were swept by the city twice each week, while the other two were left unswept. This routine was followed through the remainder of the monitoring season, terminating in mid-November. In 1981, the same two basins were swept once per week during April and May, then left unswept from June to August, after which all data collection was halted. In those last three months of monitoring, the second commercial basin and second residential basin were swept once per week. The city provided gross weights and samples of the material removed from the basins on sweeping days. The test sweeping frequencies of once and twice per week were chosen to represent probable or reasonable levels of effort from the city for cleaning residential and commercial areas.

The assumption was made that street surface dirt was the major source of urban runoff pollutants, as well as the only source controllable by street sweeping. A sampling program designed to measure the loads, particle size distributions, and constituent concentrations by particle size of the material on the streets of the basins was conducted throughout the periods of event monitoring and experimental sweeping. Twice per week on each basin, subsamples of the street load were collected from numerous locations, using a vacuum cleaner mounted in a van. The gross weight of a sample was used to calculate the total street load on a basin for that day.

The particle size distribution of the load was determined by passing the dried sample through a series of screens and recording the weight of material retained on each. The similar size fractions of samples from several days for one basin were combined for laboratory analysis of constituent concentrations in each size group. In 1981, on days of sweeping in a basin, the street load was measured both before and after sweeping was done. Throughout the period of monitoring, measurements showed that the amount and variability of street load on the commercial basins were considerably higher than on the residential basins. The particle size distributions of street loads were similar for all basins. There were greater concentrations of metals such as lead in the solids from the commercial basins and greater concentrations of nitrogen and phosphorus in the solids from the residential basins.

Effects of experimental street sweeping were expected to be noticeable in both the street load on the basins and the quality of urban runoff from them. Measurements of street load on swept basins showed a definite improvement due to sweeping, as both the amount and variability of load were substantially reduced when compared to values observed during non-sweeping periods for the same basins. The particle size distribution of solids on a basin also changed after a period of regular sweeping; coarse particles became relatively scarcer and fines relatively more abundant. This happened because the mechanical sweeper picks up large particles more effectively than small ones. As a result, regular sweeping removes more newly deposited coarse material than fine material, and the particle size distribution shifts toward the fines.

For each study basin, washoff loads and event mean concentrations (EMCs) of all available constituents were calculated for all events with reliable flow and water quality data. Initial comparisons of peak observed concentrations from discrete-sampled events showed no reduction of any constituents from swept basins. The washoff loads and EMCs were used in two basic analytical approaches. In parallel analysis, the data set considered for each pair of basins (residential and commercial) was limited to events where both basins of the pair had reliable data. These events were divided into three groups according to the street sweeping program in force when they occurred: no sweeping on either basin, sweeping on only one basin, and sweeping only on the other. Individual plots for each constituent were drawn with points representing each event's EMC or load from one basin plotted against EMC or load from the other basin. Linear regressions were run on the points grouped by sweeping practice and the resultant lines compared to determine whether for any constituent a reduction of load or EMC was evident from a swept basin. A problem with this analytical method was that there was not a great number of data points in each subgroup, since only events with good data on both basins were used, and they in turn were separated by sweeping practice. Furthermore, since there were only two full seasons of data collection, the range of event types in each subgroup was not great. The results of this analysis showed no clear indication of improvement of storm runoff quality associated with the experimental street sweeping.

In series analysis, individual data sets were developed for all four sites, consisting of all events for which there were good flow and water quality records. These included many events for each basin for which there were no good data on the paired basin, which expanded the data sets considerably. In each data set the events were separated again according to sweeping practice. For the two groups of events, loads or EMCs of single constituents were fitted to log-normal distributions and the results were plotted. The lines of one of these plots were considered representative of the characteristic washoff load or EMC of a constituent from the basin during periods of sweeping and no sweeping. The results of this analysis were no more positive than those from parallel analysis. Occasionally improvement in runoff quality appeared to be due to street sweeping, but there was not consistency of results for any constituent for all basins. The load and EMC data were sometimes contradictory for a single basin, with improvement due to sweeping indicated by one plot and not the other. In summation, there was no clear evidence of reduction of runoff loads attributable to street sweeping.

The principal conclusions of the study were as follows:

1. Mechanical street sweeping at frequencies as great as twice weekly is not effective in reducing the mean concentrations or total loads of pollutants in urban storm runoff.
2. Mechanical street sweeping at frequencies equal to or greater than once weekly reduces the amount and variability of street surface loads.
3. The mechanical street sweeper used in this study demonstrated overall removal efficiencies ranging from 30 to 67 percent of initial loads.
4. Wet deposition is a major source of several constituents in urban runoff, including ammonia-nitrogen, nitrate-nitrite nitrogen, and copper. Most other constituents of concern have no more than about 10 percent of their source in rainfall.
5. Virtually 100 percent of the ammonia-nitrogen and nitrate-nitrite nitrogen in urban runoff is dissolved and has no apparent rela-

tionship with solids. For other constituents the dissolved fraction is less: Kjeldahl nitrogen, 69 percent; phosphorus, 43 percent; copper, 32 percent; manganese, 27 percent; iron, 2 percent. Lead and nickel appear to be wholly associated with solids.

6. In all four basins, the greatest percentage of total street load, excluding gross material greater than 2000μ, falls in the size range 250-500μ. Efficient collection of particles in the size range 250-1000μ would control the bulk of the street surface load of most constituents of concern.

SECTION 1

INTRODUCTION

In 1978 the U.S. Environmental Protection Agency (USEPA) concluded that available data concerning characteristics, impacts, and control of urban runoff were inadequate for needs of planning for future development and implementation of policy and programs. To remedy this inadequacy, the agency decided to sponsor a Nationwide Urban Runoff Program (NURP). Projects were selected for 28 locations across the country to represent problems engendered by urban runoff under a variety of influences: hydrologic and climatologic conditions, land use, degree of urbanization, population, and engineering practice. All projects were located in areas which had previously identified urban runoff as a problem in areawide water quality management planning. The major effort in every project was devoted to data collection and interpretation, with special attention given to at least one of three aspects: 1) characterization of problems, including types and loads of pollutants; 2) assessment of impacts on receiving waters; and 3) evaluation of recommended control practices.

A proposal from the Illinois Environmental Protection Agency (IEPA) to test municipal street sweeping as a management practice for urban storm runoff quality was accepted for NURP by USEPA. The interest of IEPA in street sweeping as a control practice was grounded in the 208 Water Quality Management Plan for Illinois.[1] The portion of the state plan dealing with urban stormwater recommended optimization of street sweeping efforts to maximize pollutant reduction in runoff without increasing sweeping costs to a community. The plan acknowledged that development of optimization criteria depended on a more accurate assessment of the effectiveness of street sweeping in reducing runoff pollutant loads. IEPA contracted with the Illinois State Water Survey (ISWS) to perform the three-year study, which was completed in March 1982.

ACKNOWLEDGMENTS

This work was accomplished as part of the regular work of the Illinois State Water Survey under the administrative guidance of Stanley A. Changnon, Jr., Chief.

The project was initiated when Richard J. Schicht, currently Assistant Chief, was Head of Hydrology Section. The work was completed under the administrative supervision of Michael L. Terstriep, Head of Surface Water Section, who was also Principal Investigator.

The following Water Survey employees worked full-time or part-time directly on project tasks of sample collection and handling and data reduction, analysis, and interpretation: Martin Johnson, Paul Lamb, Mike Sybeldon, Carl Lonnquist, Mark Sievers, Dave Bieneman, Greg Miller, and Maureen Kwolek.

Other Water Survey staff were involved in support functions or advisory capacities. Word processing was performed by Kathy Brown, Pamela Lovett and Lynn Weiss. Illustrations were prepared by John Brother, Jr., William Motherway, and Linda Riggin. Analyses of particle size distribution in street dirt and runoff solids were carried out under supervision of Michael V. Miller, Head of Analytical Chemistry Laboratory Unit's sediment laboratory. Assistance and advice in the use of fluorometry in the rating of the flow monitoring sections were provided by Michael J. Barcelona, Head of Aquatic Chemistry Section, and Thomas G. Naymik, groundwater hydrologist. The wet-dry fallout samplers were made available through Richard G.

Semonin, Assistant Chief, and Donald F. Gatz, Head of Atmospheric Chemistry Section.

Constituent analyses of samples of runoff, atmospheric deposition, and street dirt were performed by IEPA's Champaign laboratory under the direction of Roy P. Frazier. William W. Rice of IEPA in Springfield served as contract manager.

The participation of the City of Champaign in the project was facilitated by Richard A. Larson, Director of Public Works. Steve Schaefer, City Engineer, and Jack Toombs and Oris Ward of Public Works - Operations provided advice in planning and manpower in execution of the project.

Three private citizens were engaged as cooperators in the study. Atmospheric deposition samplers and, in one case, a recording raingage were located on private property owned by William B. Collins, Robert L. Ogle, and Glenn E. Stout.

The authors are grateful to all of the above for their contributions to the project.

SCOPE OF REPORT

This project was funded and reported on in three phases. Phase I ran from June 1, 1979 through July 31, 1980[2], Phase II from August 1, 1980 through July 31, 1981[3] and Phase III from August 1, 1981 through June 30, 1982. This report documents progress of the first two phases and presents final data summaries, analysis and conclusions of the project. It should not be necessary for the reader to obtain the first two annual reports to develop a complete understanding of the project.

Phase I included the final design of the experimental procedures, acquisition of equipment, installation of equipment, and the beginning of data collection in November of 1979. Data collection was suspended briefly during the winter but reinstituted in early March. Phase II saw the completion of the 1980 data collection season, a ten-week winter shutdown, and the bulk of the 1981 data collection season. The data management system was completed early in Phase II and initial data analysis was completed. Early in Phase III it was decided to stop data collection at the end of August rather than continuing through November as originally planned. This decision was in part due to the fact that data collected this late in the project could not be reflected in the final report. It was also felt that the time and money could be better spent by moving the equipment downstream to monitor receiving water impacts. This move was accomplished in September and data collection began in October of 1981. Results of the receiving water study will be published in March 1983. Summaries of the data collected for the evaluation of street sweeping are printed in the Supplement to this Final Report.

OBJECTIVE

The primary objective of this project was to evaluate the potential conventional municipal street sweeping as a management practice for the improvement of urban stormwater quality. Goals of the project were the following:

1. To relate the accumulation of street dirt to land use, traffic count, time, and type and conditions of street surface.
2. To define the washoff of street dirt in terms of rainfall rate, flow rate, available material, particle size, slope and surface roughness.

3. To determine what fraction of pollutants occurring in stormwater runoff may be attributed to atmospheric fallout.
4. To modify the ILLUDAS model[4] to permit water quality simulation as a function of surface sediment removal.
5. To calibrate the modified model on instrumented basins.
6. To develop accurate production functions and corresponding cost functions for various levels of municipal street sweeping.

GENERAL METHODOLOGY

Five small urban basins in close proximity to one another were instrumented in the City of Champaign, Illinois. Data collection procedures included continuous measurement and water quality analysis of rainfall and runoff; chemical analysis of dry atmospheric fallout; determination of loads, rates of deposition, and rates of accumulation of street dirt; and particle size distribution and chemical analysis of street dirt.

Champaign and Urbana are adjacent cities in Champaign County in east central Illinois, figure 1.1. The combined population of the two cities is about 100,000. Separate sanitary and storm sewer networks serve the entire urban area. Both cities contain portions of the main campus of the University of Illinois. Most of the rural land in the county is devoted to agriculture, with corn and soybeans the principal crops. The soils in the area may be described as nearly level to gently sloping, somewhat poorly drained, silty soils on till plains or outwash plains. Upper reaches of three rivers, the Kaskaskia, Embarras, and Vermilion, receive drainage from Champaign-Urbana. In this area, these streams are little more than agricultural drainage ditches. Local perceptions of urban runoff problems are related more to quantity than quality, since the flatness of the

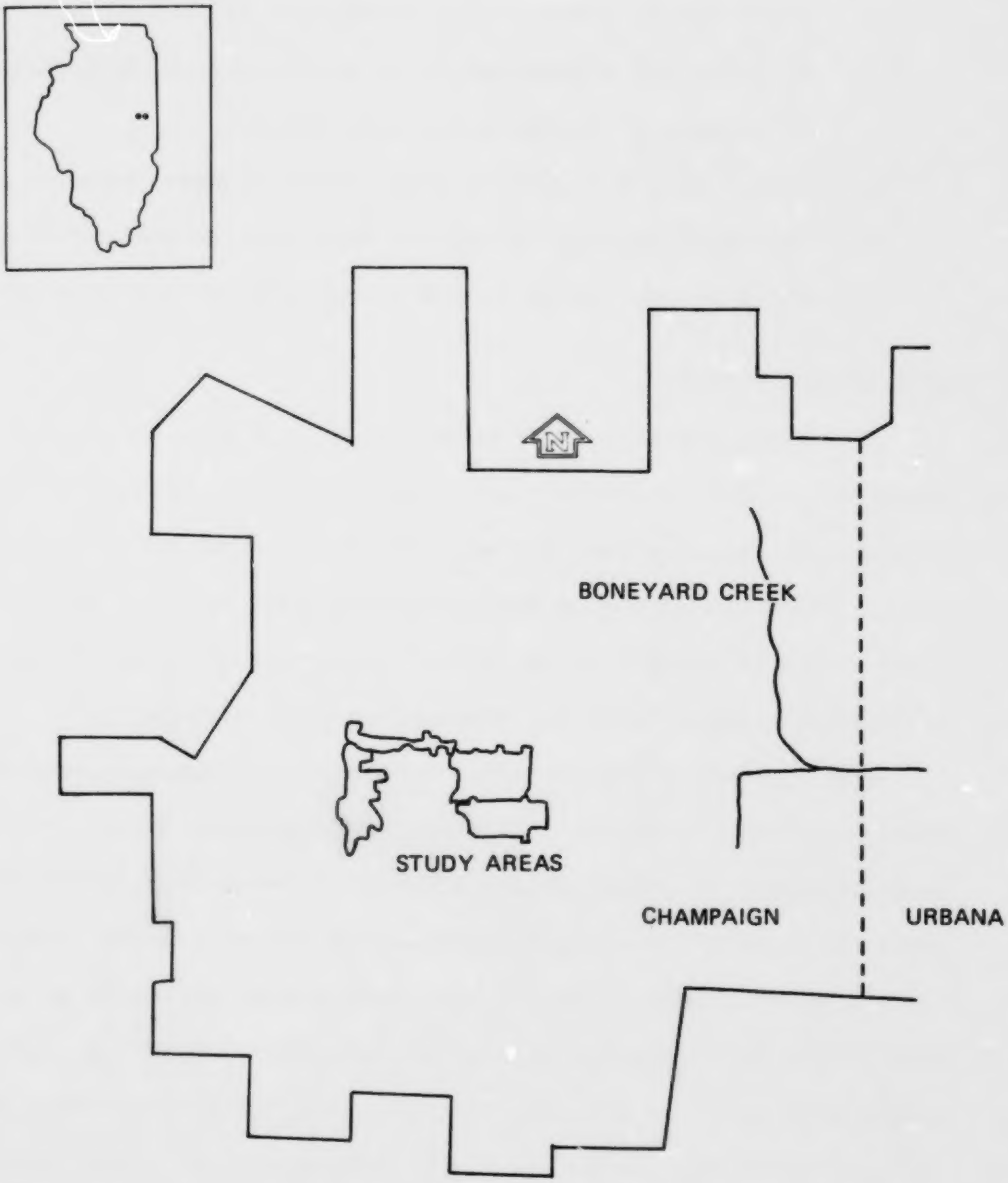
N
BONEYARD CREEK
STUDY AREAS
CHAMPAIGN
URBANA

Figure 1.1 Champaign NURP study area - general location

terrain leads to frequent flooding, while the receiving streams have limited uses.

The average annual precipitation in the Champaign area is about 36.5 inches and may be characterized as being of two basic types, frontal and convective. Frontal precipitation is the predominant type occurring from fall through early spring; it is generally widespread, with relatively low spatial and temporal variability in intensity. In contrast, convective rainfall, occurring from spring to fall, is very scattered spatially and has relatively high variability with respect to intensity. Inspection of the depth-duration-recurrence curves of figure 1.2 shows that for rainfall events of one hour or less, including most convective storms, there can be a significant amount of variability in total rainfall, evidenced by the high degree of divergence from one curve to another in this range of durations. For storms with durations greater than two hours, a group composed primarily of frontal storms, there is much less divergence between curves. This confirms the more homogeneous nature of the frontal storms.

Two of the five study basins were similar in size and had a uniform single-family residential land use. Two more basins were also similar in size and consist primarily of heavily traveled four-lane streets serving a commercial area. The remaining basin consisted of about 0.1 acre of street area contributing to a single curb inlet and was referred to as the microbasin. Since no pipe flow was involved in this basin, data from it were to be used in examination of the washoff characteristics of surface flow. The exponential washoff functions used in most current models had been shown to be inadequate for accurate simulation of the washoff phenomenon[5].

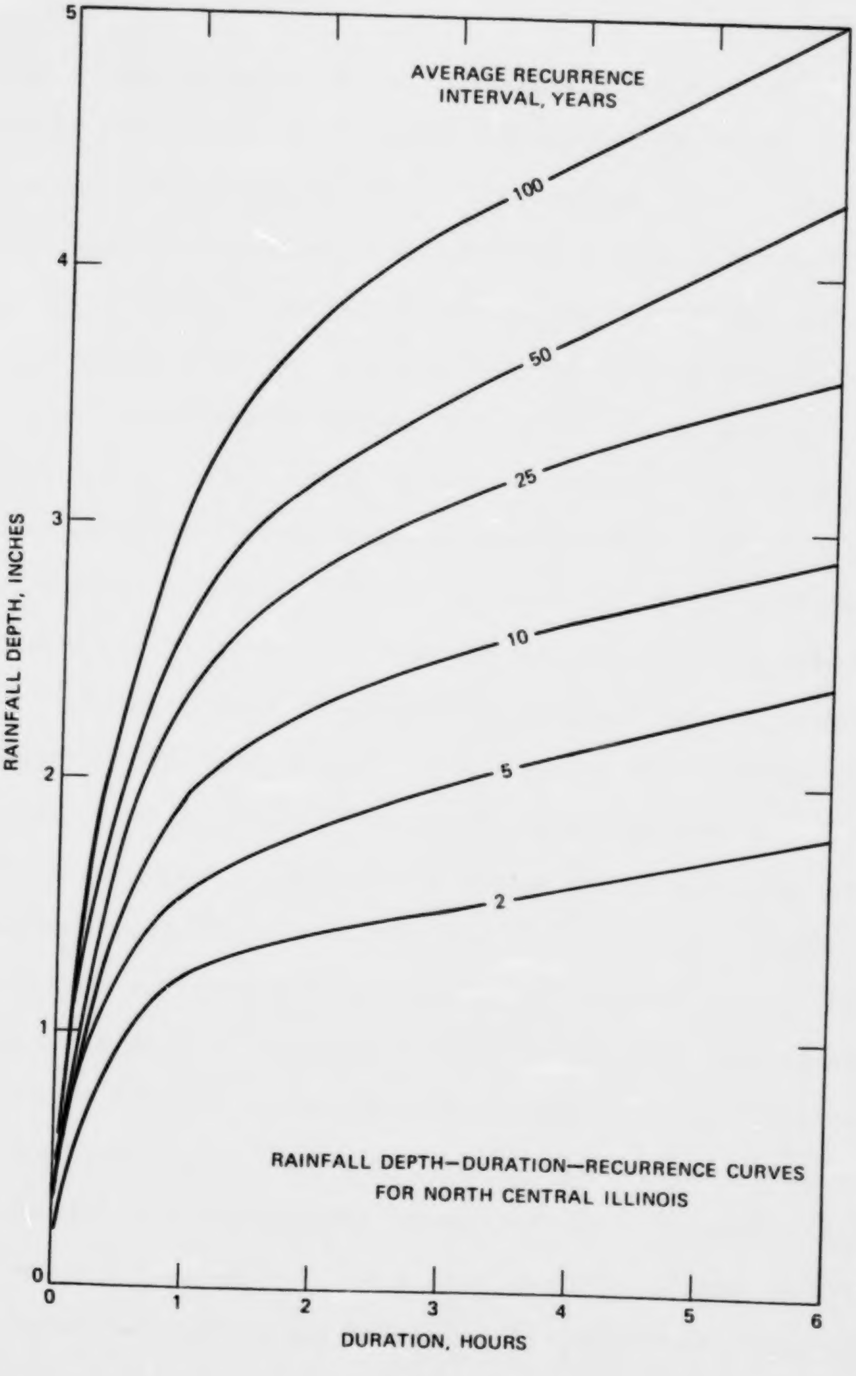

Figure 1.2 Rainfall relationships for Champaign NURP study area

Data collection began with a control period during which no street sweeping was done in any basin. The data from this period were used to establish baseline values for street dirt loads and corresponding runoff quality for each basin. After about four months of the control situation, the experimental period began. Municipal sweeping of one basin in each pair was performed at a fixed frequency, while the others remained unswept. As the project continued, the sweeping frequency was changed and the control and experimental roles of the basins were reversed. Throughout the entire experimental period monitoring of runoff quantity and quality and measurement of street dirt load, particle size distribution, and quality continued.

The potential effect of street sweeping on runoff quality was assessed in several ways. Reductions due to municipal sweeping of material available for washoff by stormwater were documented. Direct comparisons of stormwater quality from specific events on the paired basins were made. For each basin, stormwater quality for swept periods was compared with that of unswept periods. Simulation modeling was used to evaluate data, to establish the degree of validity with which paired basin results might be directly compared, and to calculate the change in runoff loads attributable to sweeping.

Two elements from this work plan will be covered in the March 1983 report on the receiving water impact study. The results of the runoff and street dirt monitoring efforts carried out on the micro-basin will be analyzed and discussed in the same way the results from the four major basins are treated in this report. There will also be a more comprehensive analysis and discussion of the character of urban storm runoff.

SECTION 2

SITE SELECTION AND INSTRUMENTATION

SITE SELECTION

The proposal by IEPA[6] to USEPA for this project contained a section describing the planned layout of study areas and sampling installations. Upon the advice of some of USEPA's Headquarters Consultants who reviewed the proposal, and after reviews of work by Pitt[7] and a related proposal for the Milwaukee NURP[8], the original criteria for site selection were modified. The guidelines which were used are summarized below.

At least two and possibly three basins were to be selected. Each was to have the following characteristics: drainage area of 40-150 acres; separate sewers, with no cross-connections or illegal discharges; one distinct land use; streets of uniform types of surface with curbs and gutters, all in good condition; and sufficient surface grade to prevent deposition in gutters or sewers of material suspended in runoff. Pairs of selected basins were to be similar in size, topography, soil type, vegetative cover, land use, age and degree of development, total impervious area, street type and condition, traffic pattern and volume, and parking. They were to be close geographically and to have no major construction planned over the life of the study. The manholes selected as the sampling sites were to have single pipes in and out, with the same diameter (larger than 15 inches), with no change in flow direction, and with no other sewer or inlet flows entering. They were also to have proper configuration and general condition suitable for installation of flow metering and automatic sampling equipment. Finally, extension of electric power and telephone service to the sites had to be feasible.

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The search for appropriate sites in Champaign-Urbana began with a map study. The cities are served by well-documented separate sanitary and storm sewer networks. Storm sewer maps were inspected to identify sites which appeared to meet the criteria for basin size, land use, and drainage configuration. About 40 such sites were found in the cities and were scheduled for closer investigation in the field.

The next step was a reconnaissance of the potential study basins, emphasizing surface characteristics. The main concern of this inspection was the condition of street surfaces, curbs, and gutters. It also permitted confirmation of the type and uniformity of land use, verification of surface grades and drainage divides estimated from topographic maps, and positive location of inlets and manholes, including some not shown on the maps. About 30 of the sites were dropped from consideration after this step. The most common reasons for disqualification were lack of curbs and gutters, incidence of large portions of undesirable street surfaces such as brick or oil and chip, and low surface grade. Ten sites survived this step to undergo further study.

The third step was examination of the manholes at the potential sites to determine their suitability for runoff monitoring. This included a check of the sizes, composition, condition, and alignment of the pipes entering and leaving the manhole; an evaluation of any interfering flows from other sewers or inlets; and an assessment of the difficulty of extending electric power and telephone service to the site. If a site was found unsuitable, nearby manholes along the same sewer were checked in an attempt to locate an acceptable site so that the basin could still be considered. It was difficult to find manholes with sewers flowing straight through without any other interfering flow entering from lateral sewers or inlets.

The result of this search was the identification of two nearly ideal basins in Champaign, numbered 4 and 5 on figure 2.1. There are two 24-inch storm sewers running eastward in parallel along John Street just west of Prospect Avenue. One is located in the center of the street, the other in the parkway on the south side of the street. At Highland Avenue both sewers are accessible by manholes which have straight-through flow and no significant interference. The basins are adjacent portions of a homogeneous residential area of west central Champaign. The curbs and gutters and street surfaces are uniform and in good condition and have reasonable surface grades.

A promising site for a micro-basin installation was found during inspection of the John Street basins. The original proposal stated that this was to be a controlled paved area of about 0.1 acre draining to a catch basin or inlet modified to hold full instrumentation for flow measurement and sampling. The results of monitoring runoff at such a site were to be used in improving representation of washoff of street dirt. The inlet which appeared satisfactory is located at the northwest corner of the intersection of Daniel and James Streets and is numbered 3 on figure 2.1.

During the field check, two additional basins were identified which showed great promise. The sampling sites were on Mattis Avenue at White Street and Sheridan Road. The basins are numbered 1 and 2, respectively, on figure 2.1. The areas draining to these points each contain about 0.5 mile of four-lane street which is subject to much heavier traffic than that in the John Street basins. The storm sewer configuration at the Mattis sites was ideal for flow monitoring. When ISWS suggested that it would enhance the study to monitor a second pair of basins with different land use and traffic characteristics than were found in the John Street areas,

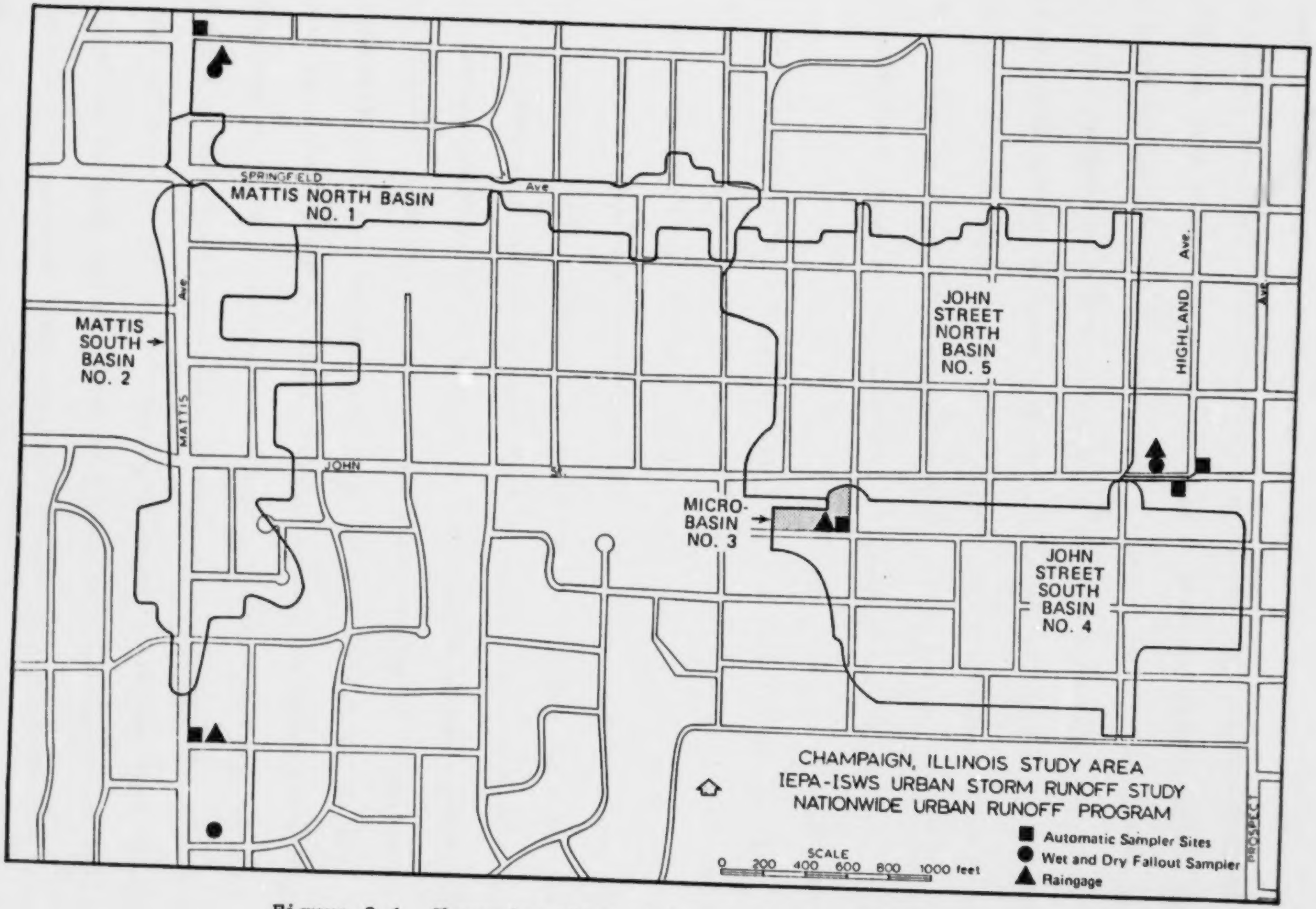
SPRINGFIELD Ave
MATTIS NORTH BASIN NO. 1
MATTIS SOUTH BASIN NO. 2
MATTIS Ave
JOHN St.
MICRO-BASIN NO. 3
JOHN STREET NORTH BASIN NO. 5
JOHN STREET SOUTH BASIN NO. 4
HIGHLAND Ave.
PROSPECT Ave.
CHAMPAIGN, ILLINOIS STUDY AREA
IEPA-ISWS URBAN STORM RUNOFF STUDY
NATIONWIDE URBAN RUNOFF PROGRAM
■ Automatic Sampler Sites
● Wet and Dry Fallout Sampler
▲ Raingage
SCALE
0 200 400 600 800 1000 feet

Figure 2.1 Champaign NURP study area - basin boundaries and instrument locations

IEPA agreed and expanded the work plan to allow for the additional equipment and sampling effort required.

Inquiries were next made to Illinois Power Company and Illinois Bell Telephone Company about the feasibility of extending electric power and telephone service to the recommended sites. Power requirements were estimated at a maximum of 28 amps of 120-volt current for operation of each sampling and monitoring station. A dedicated telephone line was required for the telemetry system which will be described below. For all proposed sites the companies indicated that the necessary service could be supplied but that they would not be responsible for running underground lines from poles to the sites.

The City of Champaign was aware of the site selection process and were presented with the site selections. The Director of Public Works and the City Engineer were receptive to the plan of study as outlined by ISWS. They found no fault with the selection of the five sites and foresaw no major problems with installation of monitoring equipment; in fact, they made many helpful suggestions which were incorporated during installation. Cooperation of the Public Works Department of the City of Champaign was critical to the success of this project. They were therefore brought into the planning process early in the project and kept informed of the site selection progress. It was necessary to attach parts of the monitoring equipment to the city storm sewers and to install the bulk of the equipment on city street right-of-way. The city cooperated fully in authorizing the use of city property. The City Council's quick approval of the requests and the involvement of the Public Works Department contributed greatly to the success of the project. The City Engineer's office evaluated all sites with regard to line of sight interference with traffic and other potential conflicts with city uses.

COMPARISON OF BASINS

Table 2.1 contains physical parameters of the study basins. The total drainage area contributing to runoff at the sampling point is given first. The percentage of the total area in three major categories follows. Directly connected impervious area represents all streets, sidewalks, driveways, rooftops, and parking areas from which runoff travels to the drainage system without crossing any pervious areas. Supplemental impervious area is the remainder of the impervious area in the basin, from which runoff may only reach the drainage system by flowing across lawns or other pervious surfaces. Grassed area refers to all pervious areas in the basin, including lawns, gardens, and parks. The values for percent roadway, lane miles, and curb miles identify in terms of area and length the portion of each basin given over to streets, curbs, and gutters. The roadway areas range from 13 to 26 percent of the total basin areas and in all cases constitute large parts of the directly connected impervious area. Basin slope values are based on the longest primary flow path in each basin. The fall in elevation and length of the complete path is used for calculating total basin slope. The second slope value is calculated from the fall and length of the same path between points 15 percent and 85 percent of the total length upstream from the outlet. Additional basin data are given in the Supplement to this report, the data summary.

TABLE 2.1. Comparison of Physical Basin Parameters

Parameters	Mattis North	Mattis South	John North	John South	Micro Basin
Total Area (acres)	16.7	27.6	54.5	39.1	0.76
Directly Connected Imperv. Area (% of Total)	58.0	40.0	18.5	17.5	18.0
Roadway (% of Total)	26	21	14	13.4	15
Lane Miles	2.70	3.21	4.79	3.36	0.07
Curb Miles	1.15	1.33	4.79	3.36	0.07
Supplemental Imperv. Area (% of Total)	3	11	14.5	14.7	18
Grassed Area (% of Total)	39	49	67	67.8	64
Basin Slope (% of Total)	.54	1.2	.67	1.31	1.75
Fall (ft)	17.5	29.8	21.9	33.3	6.1
Length (ft)	3255	2480	3260	2535	350
Slope 15-85 (% of Total)	.51	1.27	.69	1.52	
Fall (ft)	11.6	22	15.9	26.9	
Length (ft)	2280	1735	2285	1775	

Figures 2.2 and 2.3 illustrate the commercial land use and dominant street area in the Mattis North and Mattis South basins respectively. Although table 2.1 shows that the Mattis basins are somewhat dissimilar, their selection was based on physical similarities that are not easily tabulated. These include the facts that both basins contain approximately two lane miles of high-traffic roadway, both have been re-sewered in the past ten to fifteen years with no apparent hydraulic problems, and both have a good mix of both commuter and commercial traffic.

Figures 2.4 and 2.5 illustrate the uniform single family land use that exists in the John South and John North basins as well as the micro-basin. The two John Street basins are a well-matched pair, with the exception of

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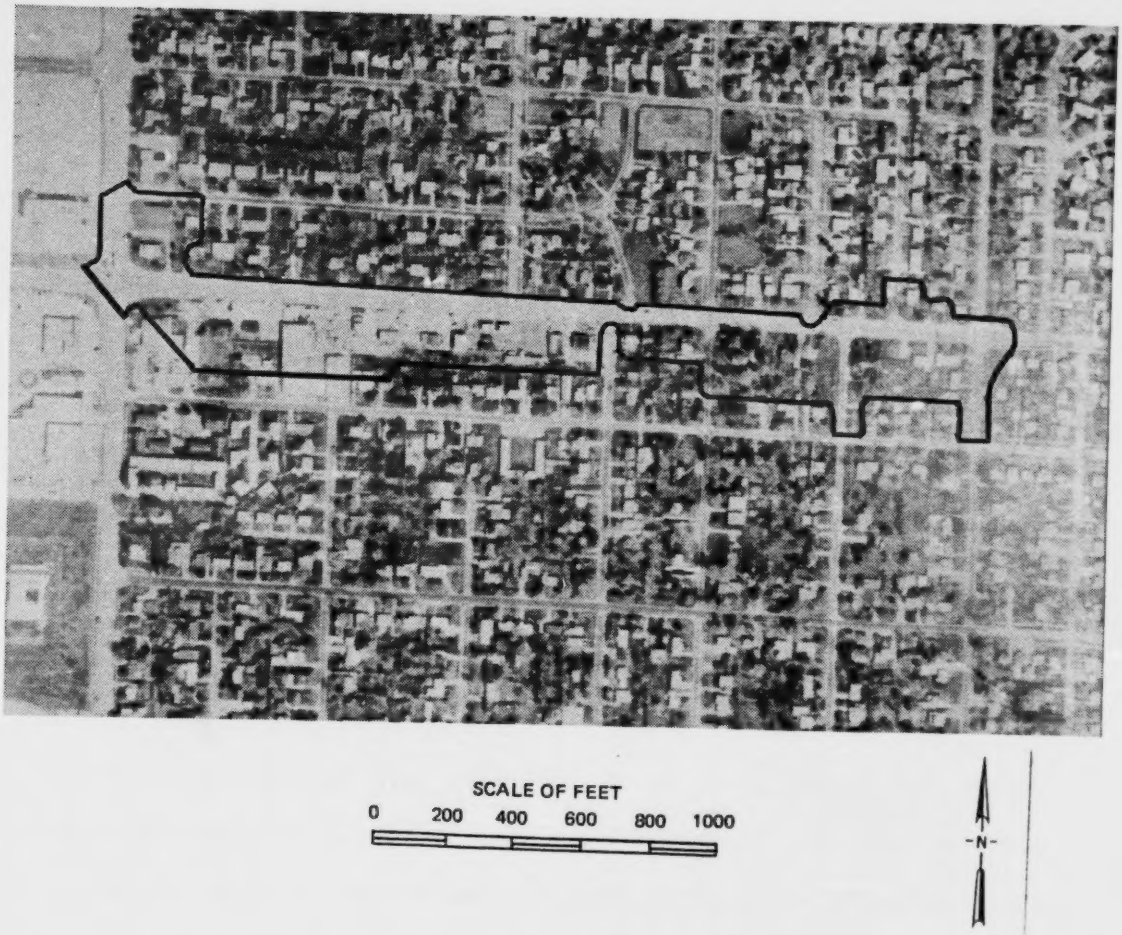
SCALE OF FEET
0
200
400
600
800
1000
N

Figure 2.2 Mattis North Basin - site 1

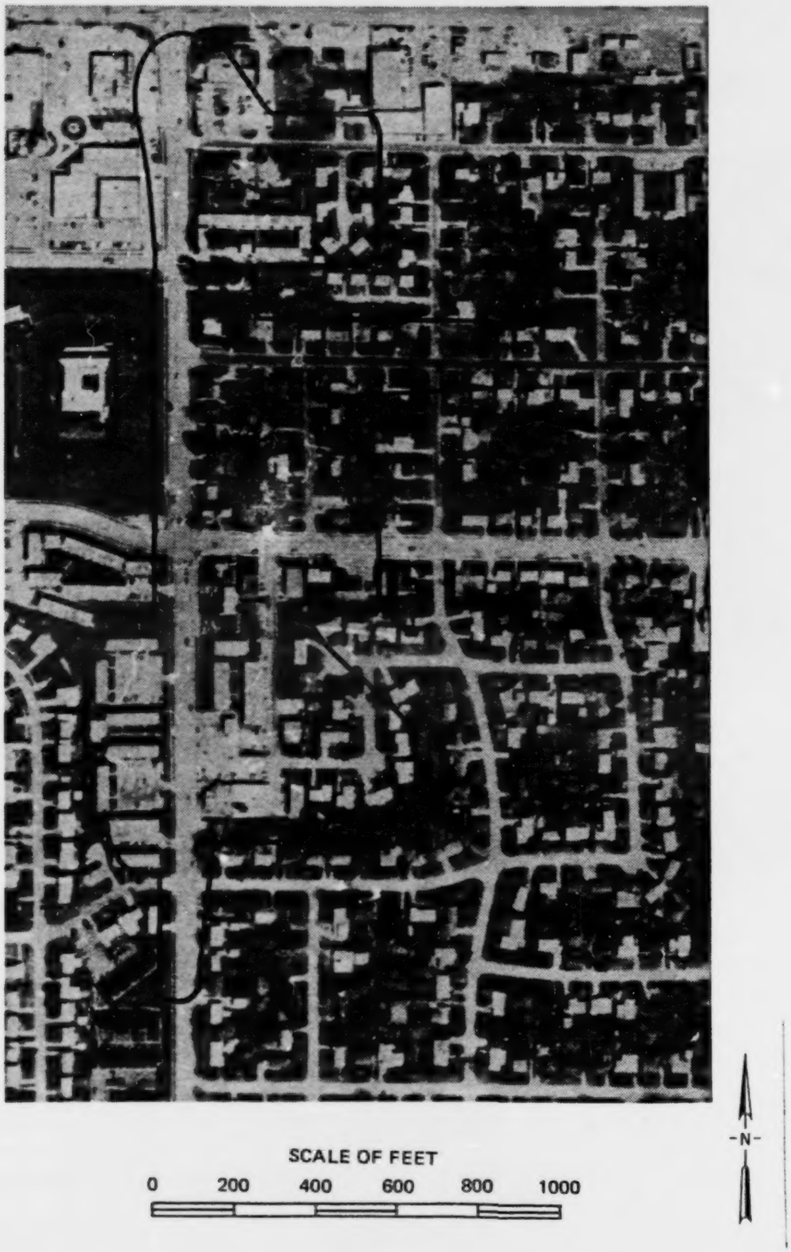
SCALE OF FEET
0
200
400
600
800
1000
N

Figure 2.3 Mattis South Basin - site 2

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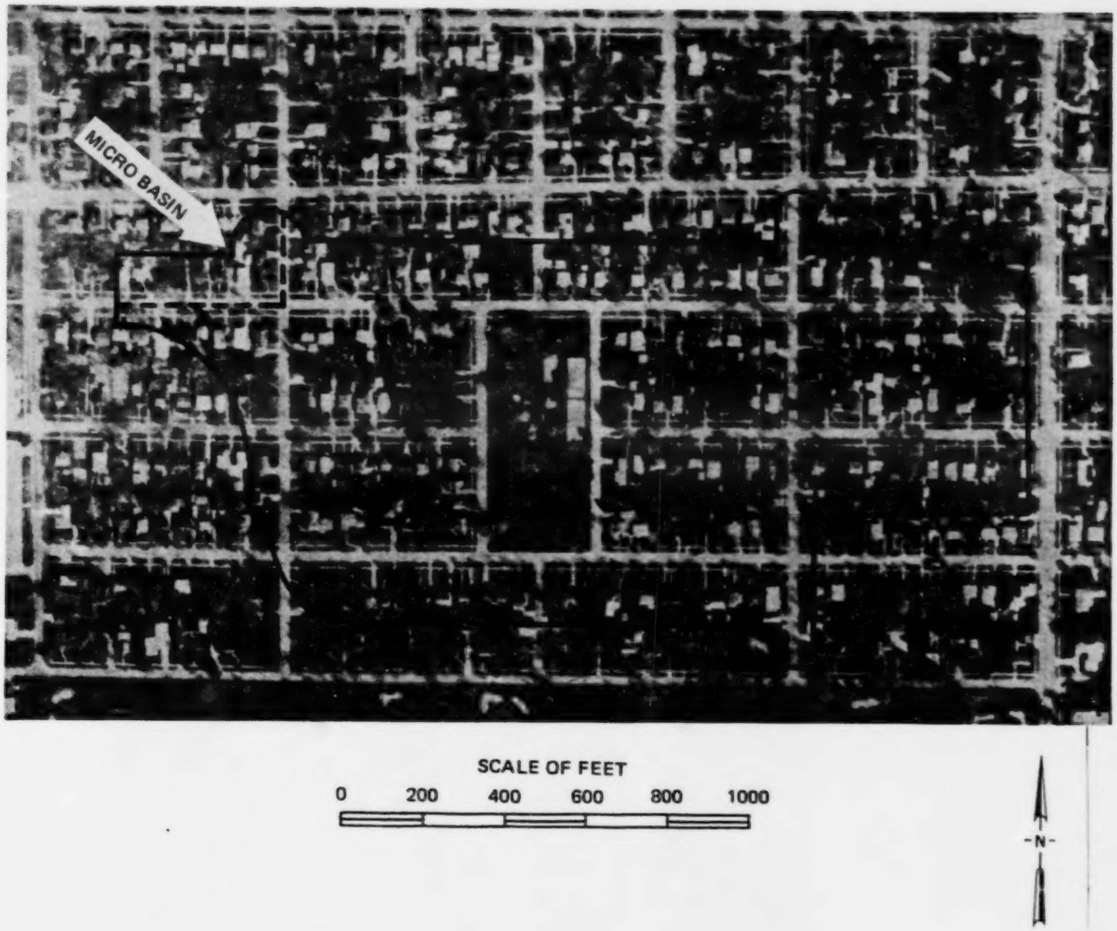
MICRO BASIN
SCALE OF FEET
0
200
400
600
800
1000
N

Figure 2.4 John South Basin - site 4

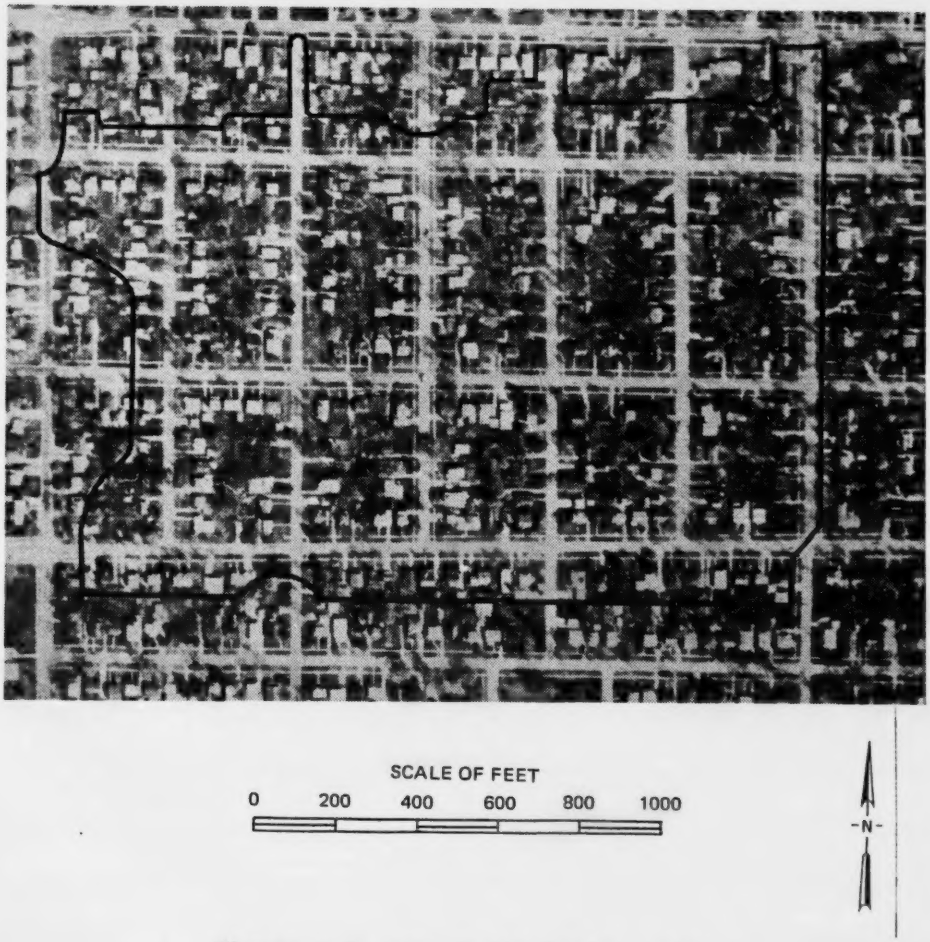
SCALE OF FEET
0
200
400
600
800
1000
-N-

Figure 2.5 John North Basin - site 5

overall basin slope. The micro-basin is representative of both basins. The traffic in both basins is basically local residential and commuter, although John North contains the more highly traveled commuter thoroughfares. There are hydraulic problems creating local flooding in both basins, particularly in John South, where there is a significant problem due to undersized pipes. Computer simulation was used to determine the degree of hydraulic similarity of both pairs of basins.

EQUIPMENT SELECTION

In this section all of the major equipment items necessary to collect the data required for this project are described. In general, flow measurement and sampler control at all five basins and raingages at three locations were tied into a telemetry system. In addition to the equipment purchased for this project, three wet-dry samplers and one recording raingage were supplied by ISWS. Other equipment described was for use in the street dirt sampling and sieving process.

Telemetry Network

A decision was made at the time that the original proposal was written to utilize telemetry in the data collection network. The heart of a telemetry network is a mini-computer with a typewriter style keyboard for input, a printer for output, and a magnetic storage device utilizing cassette tape or floppy disk. These items can all be placed on a desk top in a convenient location and are referred to as the central station. The central station is connected by leased phone lines to one or more remote stations. A remote station is an electrical device that can receive signals from raingages, depth sensors or temperature sensors and communicate these signals back to the central station. The remote station can also start up electrical devices such as pumps or motors on command from the central station. The remote station must be wired directly to the devices with which it communicates or which it controls. For this reason the remote station is usually located within a few hundred feet of these various devices.

Some advantages of a telemetry system in this kind of a project are the following:

1. All raingages, depth sensors and samplers operate on a single clock located in the central station. Synchronization of data is automatic and precise.
2. Data are recorded directly into magnetic storage, eliminating any chart reading operations.
3. Status checks of the instruments are made automatically every 60 minutes, 24 hours a day. The system can also be checked or operated from the office. This helps to avoid instrumentation being down when an event occurs.
4. Event simulations can be compared with observed values after an event has occurred.
5. Additional cost of equipment is offset by reduction in manpower.

Disadvantages include the reliance upon a number of manufacturers for pieces of equipment that must interface electrically with each other. A further disadvantage is the necessity for a highly skilled individual to set up, program, and trouble-shoot the system.

Central Station--

1. Computer - Heath H-11A with 32K RAM, a real time clock, and BASIC language compiler.

2. Input/Output - A Texas Instruments model 745 hard copy data terminal.

3. Storage - Heath dual floppy disk system with controller and operating system. Each standard 8 inch disk contains 256 K bytes of storages.

4. Interface - EMR Recon II number 3283 from Sangamo Weston. This is a device capable of receiving phone line signals from and transmitting signals to a remote station.

Remote Station--

Recon II remote from Sangamo Weston, a device capable of receiving hard wire signals with at least 8 separate addresses of the following types:

1. Status/Alarm: 8 Status/Alarm inputs for relay closure.
2. Analog: 6 points, 0-5 volt, 0-4 milliamp (ma), and 4-20 ma, 8 bit coding accuracy through the central station ± 0.5% or better.
3. Control: 4 two-state or 8 unitary controls, contact closure rated at least 200 ma and 30 volts for 200 milliseconds.
4. Pulse Accumulator: accepts one tipping bucket raingage signal and provides accumulation of up to 255 pulses before reset; capable of interrogation at anytime without affecting count; two registers to prevent overflow.

Four of these remote stations were required to provide communication with all of the raingages, depth sensors and samplers in the network. A schematic of the telemetry system including the samplers, raingages, and bubblers described below is shown in figure 2.6.

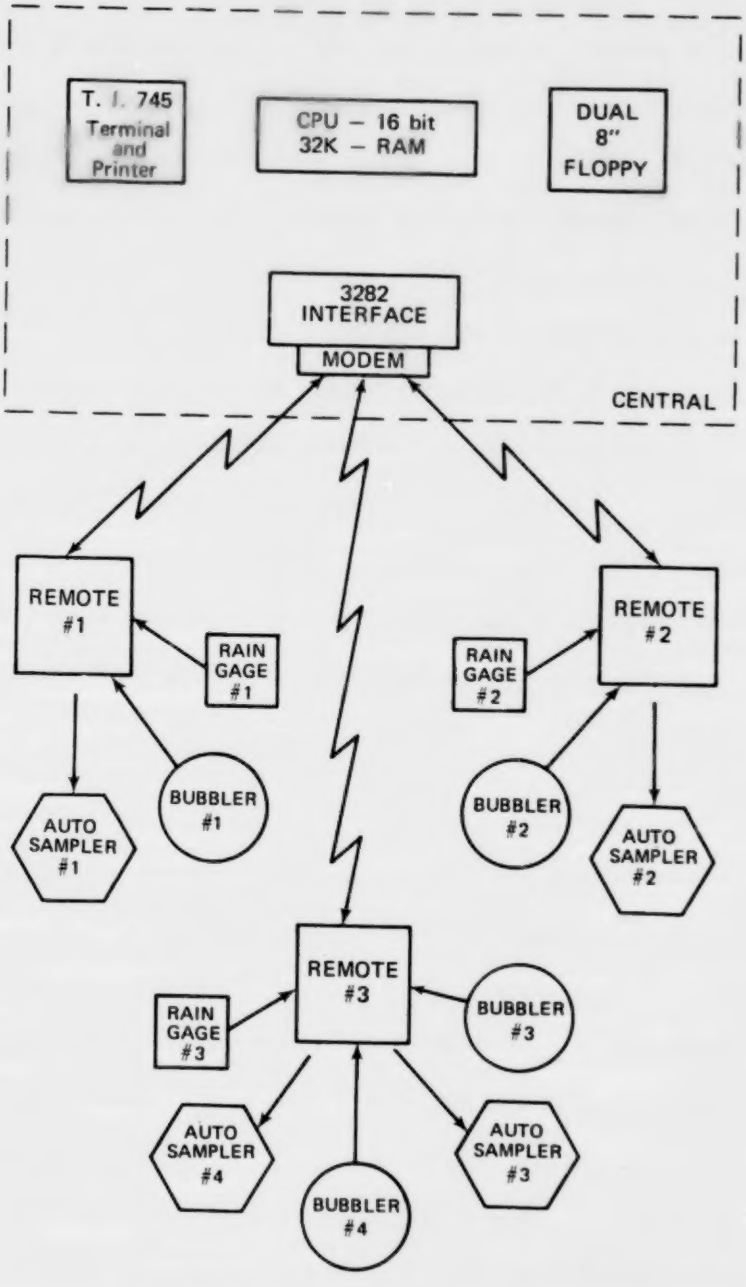
T. I. 745
Terminal and Printer
CPU – 16 bit
32K – RAM
DUAL 8" FLOPPY
3282 INTERFACE
MODEM
CENTRAL
REMOTE #1
RAIN GAGE #1
AUTO SAMPLER #1
BUBBLER #1
REMOTE #2
RAIN GAGE #2
BUBBLER #2
AUTO SAMPLER #2
REMOTE #3
RAIN GAGE #3
BUBBLER #3
AUTO SAMPLER #4
BUBBLER #4
AUTO SAMPLER #3

Figure 2.6 Schematic diagram of telemetry system

Bubbler (Flow Measurement)--

Flow measurement is accomplished by measuring depth of flow approaching a control section. The control section can be created by installation of a partial restriction to flow in the pipes or can occur at a free overfall section. Both of these methods are utilized and are described under installation of equipment. The device selected to measure depth was the Sigmamotor LMS-300 level recorder. It operates on 110 volt AC, has its own compressor and has an accuracy of ± 1% or better in an operating range of 0 to 3 feet of head. The bubbler outputs a 4-20 ma signal to the telemetry remote. The signal is proportional to the pressure required to force a bubble of air through an orifice located at the invert of the storm sewer. That pressure is in turn proportional to the depth of flow over the orifice. The LMS-300 is also equipped with a small chart recorder which is used for backup and to check the instrument's performance in the field.

Automatic Sampler--

The automatic sampler must be able to withdraw a sample of water from the storm sewer on command from the remote station and store this sample of water in a refrigerator until it can be picked up and transported to the laboratory. The unit used in this study was the Sigmamotor 6301 refrigerated sampler. Upon receiving a signal to take a sample the 3/8 inch suction line is air purged, a sample is pumped, the line is purged again, and the sampler positions itself for the next sample. Samples are limited to 24 500-ml bottles. A peristaltic pump is used so that the sample only contacts the Tygon tubing and the latex tubing used in the suction line.

Equipment Shelter--

At each of the sampling points the remote station, one or more bubblers, and the automatic sampling device were housed in a two-door fiberglass shelter approximately 4 feet square and 4.5 feet tall. A typical installation is shown in figure 2.7. The shelter is a Western Power Products Model 42-2. It has one inch of foam insulation and a thermostatically controlled exhaust fan for temperature control in the summer.

Raingage--

Three Weather Measure P-501 tipping bucket raingages were part of the telemetry network. The 8-inch diameter collector funnels the rainwater to a dual cup device that holds 0.01 inch of water. As one of these cups fills, the device tips to empty it and begin filling the other cup. The tip causes a mercury switch closure which is transmitted to the accumulator in the remote as 0.01 inch of rain.

Wet-Dry Fallout--

These devices, shown in figure 2.8, were manufactured and lent to the project by ISWS. Similar devices are available commercially. Two plastic buckets are installed on a frame about one meter above ground. A lid covers one bucket and exposes the other to dry fallout. A sensor on the lid detects rain and the lid moves to cover the dry fallout bucket and expose the other bucket to catch a rainfall sample. After rainfall ceases, the lid again moves and exposes the dry fallout bucket.

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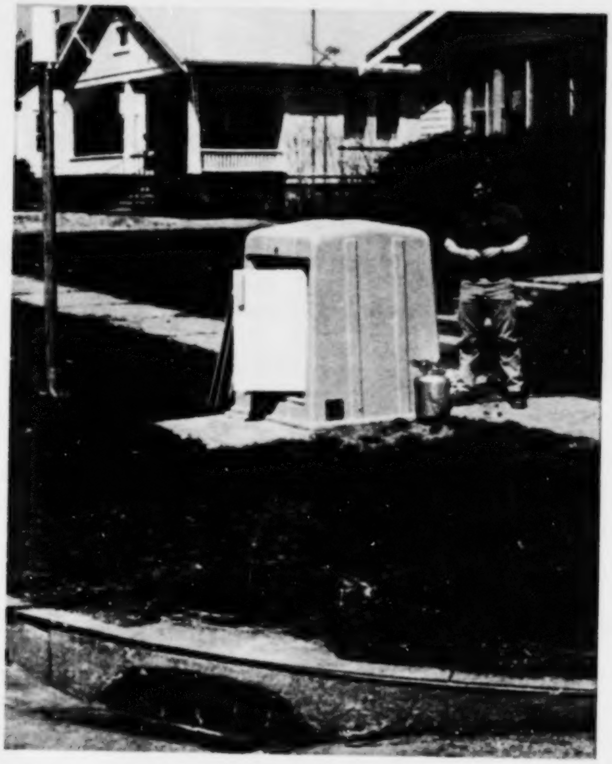

Figure 2.7 Typical above-ground installation

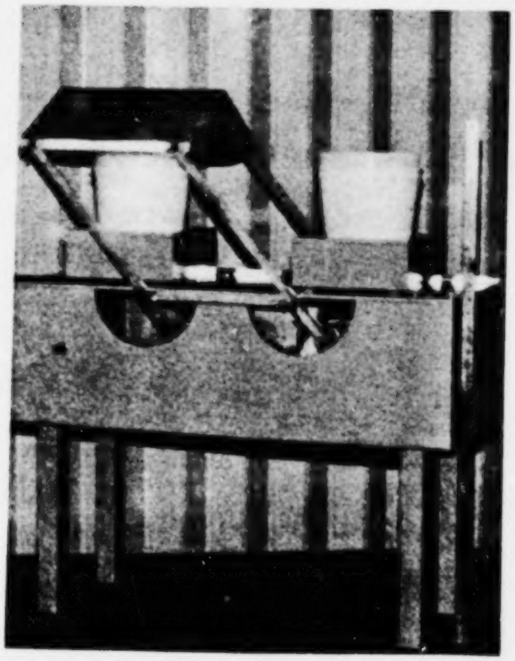

Figure 2.8 Wet-dry fallout sampler

Street Dirt Sampling Equipment

Samples of street dirt were collected by running a shop-type vacuum cleaner over selected strips of pavement from curb to curb. This procedure required a vacuum, a generator, and a vehicle to move this equipment from site to site. Additional equipment was required for sieve analysis of the sample upon returning to the lab.

Vacuum--

A Hild Model 730 Industrial Vacuum consisting of a 30 gallon stainless steel tank, a 2.3 hp motor, 20 ft of 4-inch vinyl hose, a 4-foot aluminum wand with a 6-inch floor tool, and a dynel cloth filter (cotton/nylon blend).

Generator--

A Lincoln Model K-1282 Welder-Generator with a Kohler Model K-241P 10 hp engine rated at 4500 watts AC.

Truck--

The vacuum and generator were mounted in a 1980 Dodge Van equipped with a yellow strobe light for safety.

Sieving--

Stainless Steel sieves by W.S. Tyler were used on a Combs Type HL Gyratory Sifting Machine. It is made by Great Western Manufacturing Company and is equipped with a 1/6 hp motor.

INSTALLATION OF EQUIPMENT

A number of constraints were involved in the installation of equipment for this project. Each of the five sampling points shown in figure

2.1 required power and four of the five required telephone service for the telemetry. The power company required individual meters for each site, to be positioned on poles owned by the project. Since each of the shelters was to be served underground by power and phone to avoid additional clutter around the site, both overhead and underground wiring was involved at each site. Wiring also had to meet city codes and was therefore sublet to a private contractor. Additional constraints were imposed on the location of instrument shelters. Site selection had shown that there were very limited opportunities for flow measurement. The shelters had to be located within 50 feet of these specific flow measuring sites and also had to be located on street right-of-way. Care was taken not to block vision at intersections or from private driveways. Locations also had to receive the general approval of adjacent land owners.

Some means had to be available to route the bubbler line and sampler vacuum line from the shelter to the sampling point within the storm sewer. This was normally achieved by entering the back side of a curb and gutter inlet and routing the tubing through the existing pipe connecting the inlet to the manhole.

Location of sites with proper exposure for raingage installation was also difficult because of the number of trees and shrubs planted in this older residential area. Three of the four raingages were part of the telemetry network and had to be hardwired to the remote units. The following sections describe the installations in more detail.

Site 1 and 2, Mattis North and Mattis South

Figure 2.9 shows the type of underground installation used for both sites 1 and 2. The free overfall available at these sites was utilized in

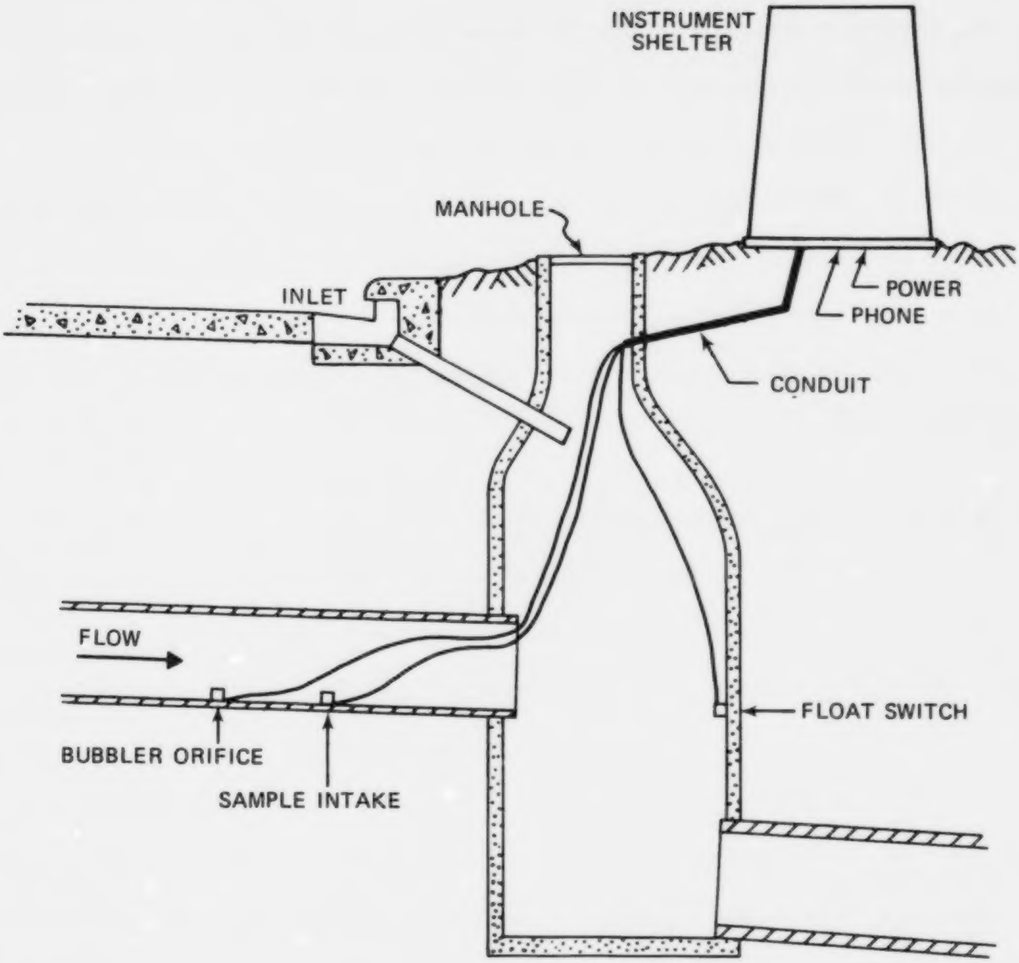
INSTRUMENT SHELTER
MANHOLE
INLET
POWER
PHONE
CONDUIT
FLOW
FLOAT SWITCH
BUBBLER ORIFICE
SAMPLE INTAKE

Figure 2.9 Underground installation at Mattis basins

lieu of a restrictive section to create critical depth. A single bubbler located at least three diameters above the free overfall was used to determine the normal depth. A float switch located at the invert elevation in the manhole was used to indicate submergence of the free overfall. Submergence of the overfall would invalidate measurements at these sites. Site 1 also included a weighing type raingage that was not connected to the telemetry network. The raingage was located adjacent to wet-dry and bulk rainfall samplers on private property as indicated in figure 2.1. Site 2 includes a raingage located about 8 feet above ground level on the street right-of-way and wet-dry fallout and bulk rainfall samplers on private property.

Sites 4 and 5, John South and John North

The underground installations for sites 4 and 5 were similar and are shown in figure 2.10. A modified asymmetric flume described by Wenzel[9] was selected for these sites. The asymmetric flume creates a restricted section which provides critical depth at less than full flow and acts as a Venturi section during pressure flow. The flume was constructed by bolting 1/4 inch aluminum plate to the storm sewer side wall. Rating for the pressure flow condition required bubblers upstream from the transition section and in the center of the restricted section. The asymmetric flume had the advantage of an unrestricted invert and proved to be self-cleaning. Theoretical rating of the flume is covered in a later section. Associated with sites 4 and 5 are a telemetered raingage and wet-dry fallout and bulk rainfall sampler located on private property.

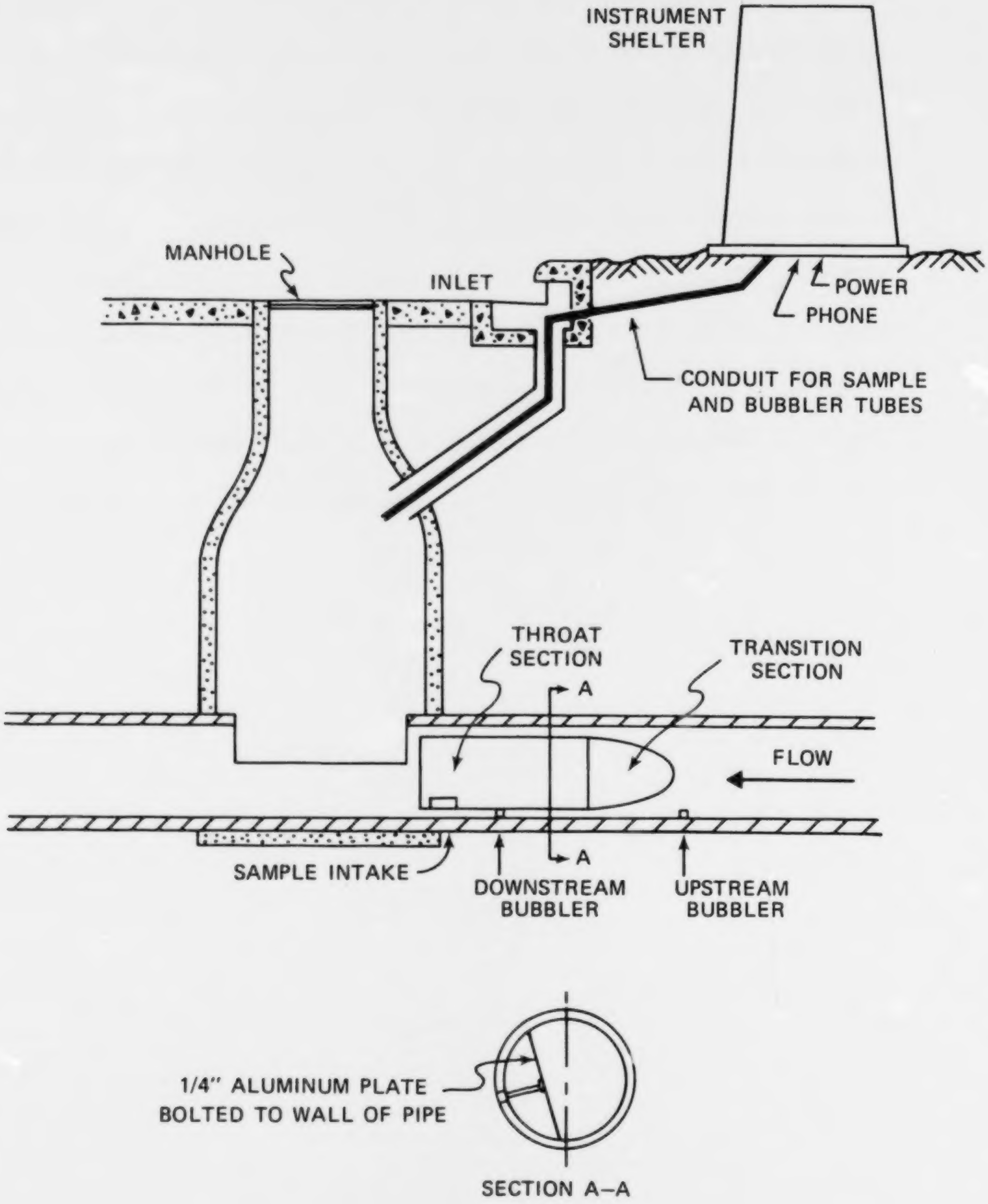
INSTRUMENT SHELTER
MANHOLE
INLET
POWER
PHONE
CONDUIT FOR SAMPLE AND BUBBLER TUBES
THROAT SECTION
TRANSITION SECTION
A
FLOW
A
SAMPLE INTAKE
DOWNSTREAM BUBBLER
UPSTREAM BUBBLER
1/4" ALUMINUM PLATE BOLTED TO WALL OF PIPE
SECTION A–A

Figure 2.10 Underground installation at John basins

Site 3, Micro-basin

Flow measurement and runoff sampling were required at this site, a combination curb and gutter inlet. Figure 2.11 shows the configuration of this site. The inlet was badly deteriorated and was completely rebuilt for purposes of flow measurement. The inlet was reformed by the City and an 8-inch concrete pipe installed by ISWS between the inlet and adjacent manhole. Prior to installation a bubbler orifice was installed in the concrete pipe approximately 30 inches upstream from the free overfall. The sampler intake tube was located at the mouth of the concrete pipe near the bottom of the inlet. A telemetered raingage located 8 feet above ground level on the street right-of-way was associated with this site.

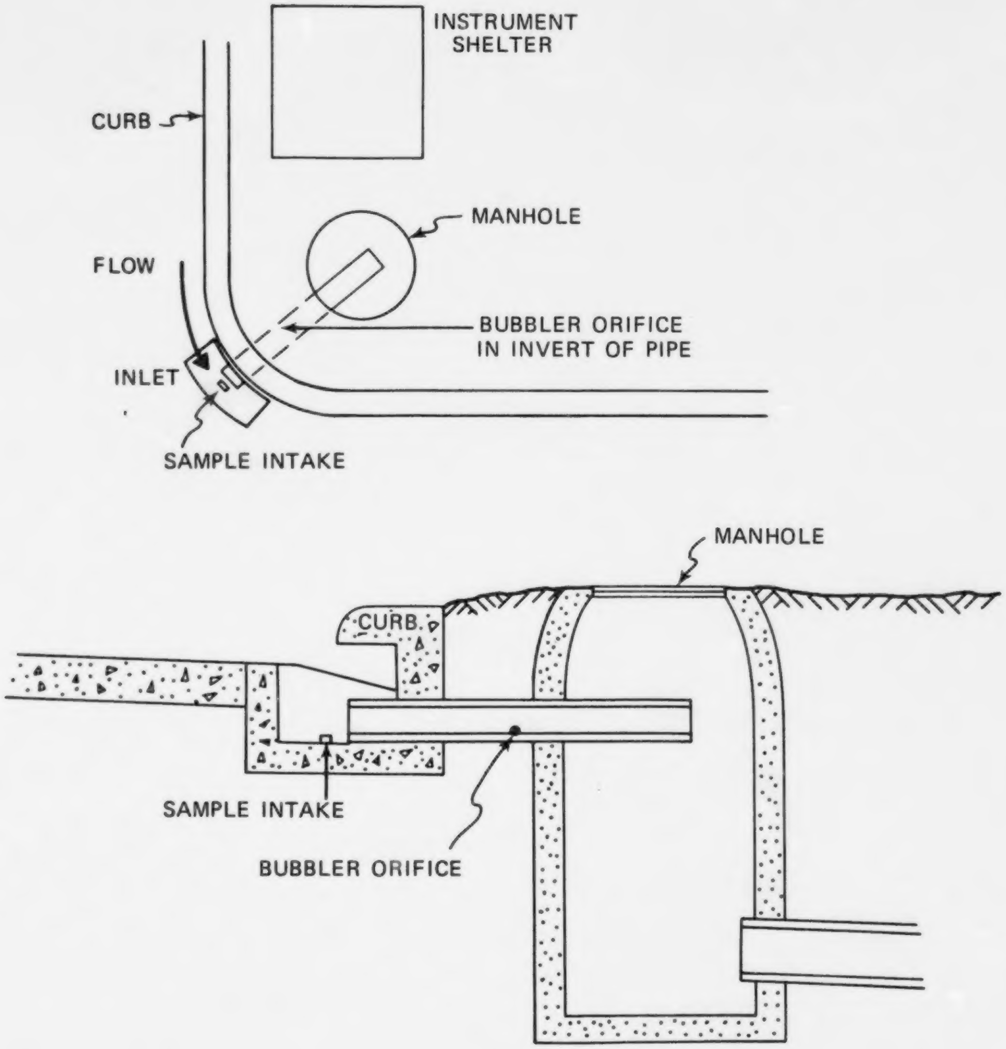
INSTRUMENT SHELTER
CURB
MANHOLE
FLOW
BUBBLER ORIFICE IN INVERT OF PIPE
INLET
SAMPLE INTAKE
MANHOLE
CURB
SAMPLE INTAKE
BUBBLER ORIFICE

Figure 2.11 Underground installation at micro-basin

SECTION 3

METHODOLOGY

DATA COLLECTION

Data collection efforts were of two types, wet weather and dry weather. In wet weather, rainfall over the entire area and storm runoff from the study basins were monitored and recorded, and samples of rainfall and runoff were taken for water quality analyses. In dry weather, samples of the accumulated street dirt were collected in all basins for determination of the load, particle size distribution, and constituent concentration. Atmospheric fallout samples were collected through both wet and dry periods.

Runoff Event Monitoring

The automatic data collection system for monitoring runoff events was operated constantly except for short periods during dry days when the Heath H11A computer was required for other tasks, such as data manipulation and field equipment status checks. The operation of the system produced a continuous record of precipitation of three rain gages and depths of flow at the five sampling points in the study areas. Precipitation data were reported in increments of 0.01 inch; depth of flow data were reported in units of 0.01 foot for seven locations, two each at sites 4 and 5. These data were obtained at one-minute intervals. The precipitation record was supplemented by data from two recording raingages, one the ISWS gage installed at the home of a cooperator near site 1, the other a U.S. Weather Bureau gage at Urbana Morrow Plots on the campus of the University of Illinois. The charts from the ISWS gage were read to the nearest 0.01 inch at five minute intervals; the charts from the Weather Bureau gage were

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read to the nearest 0.01 inch at fifteen minute intervals. The computer program RUNOFF was used by the Heath H11A computer to monitor the automatic equipment in the study areas, to control the samplers during runoff events, and to store event data reported by the telemetry network. The original version of RUNOFF was developed by ISWS in November 1979. Many subsequent improvements were made but the final version performed the monitor and control functions in fundamentally the same way as did the original. The chief improvements were made to the routines for storage and manipulation of event information. Figure 3.1 is a simplified flow chart of the monitor and control functions of RUNOFF.

There were two modes of operation in RUNOFF, called WAIT and EVENT. When the system was activated and monitoring was begun, the WAIT mode was in control. After printing to the terminal the depths at the moment of startup at the seven depth monitoring points in the study area, the program checked the pulse accumulators connected to the tipping bucket raingages at sites 2, 3, and 4. If the accumulators showed no indication of precipitation, the program waited for one minute and repeated the check of the accumulators. As long as there was no evidence of precipitation, the program would continue checking the raingage accumulators every minute and printing the depths at the monitoring points every 60 minutes from the start time. None of the data printed during the WAIT mode was written to disk storage.

If there was a tip of raingage bucket registered at any one of the sites 2, 3, or 4, control was shifted from WAIT to EVENT mode. Under this control the one-minute interrogation of the remote stations continued, with five-minute summaries of rainfall and depth of flow being printed. During discrete sampling operation, the five automatic samplers were instructed to

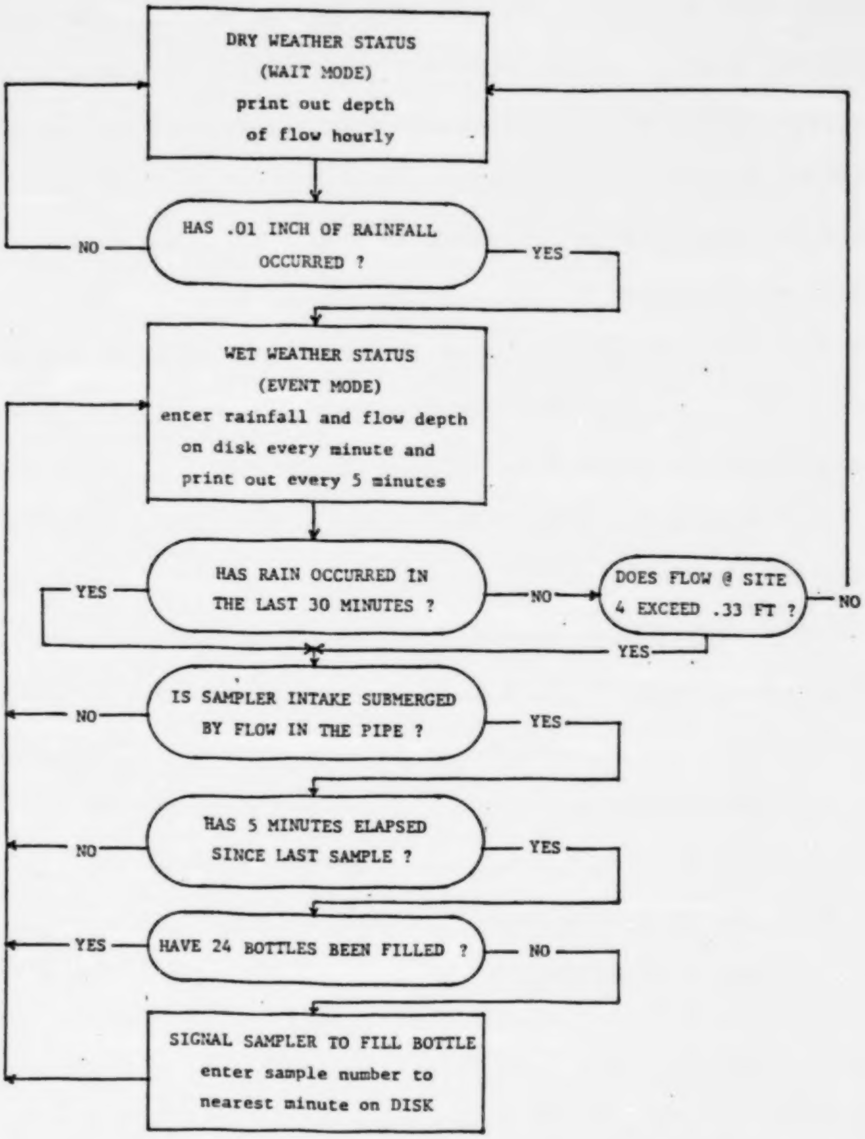
DRY WEATHER STATUS
(WAIT MODE)
print out depth
of flow hourly
HAS .01 INCH OF RAINFALL
OCCURRED ?
NO
YES
WET WEATHER STATUS
(EVENT MODE)
enter rainfall and flow depth
on disk every minute and
print out every 5 minutes
HAS RAIN OCCURRED IN
THE LAST 30 MINUTES ?
YES
NO
DOES FLOW @ SITE
4 EXCEED .33 FT ?
NO
YES
IS SAMPLER INTAKE SUBMERGED
BY FLOW IN THE PIPE ?
NO
YES
HAS 5 MINUTES ELAPSED
SINCE LAST SAMPLE ?
NO
YES
HAVE 24 BOTTLES BEEN FILLED ?
YES
NO
SIGNAL SAMPLER TO FILL BOTTLE
enter sample number to
nearest minute on DISK

Figure 3.1 Flow chart of program RUNOFF

sample at five-minute intervals while the runoff flows submerged the sampler intakes. For flow-weighted composite sampling operation, the samplers were triggered each time specific volumes of runoff had passed the monitoring points, and the samples ordered at any site were collected in one large container. The one-minute data obtained by the telemetry system, including precipitation accumulation, depth of flow, and current sample number for each site, were written to disk storage and saved. If an event lasted long enough to exhaust the capacity of a sampler, fresh bottles could be installed and the sample number counter reset by the field crew. An event was considered over and the EVENT mode terminated when no additional bucket tips had registered at any raingage for 30 minutes and the upstream depth at site 4, the outlet of the slowest draining sewer network found in the four study areas, had dropped below 0.33 foot. At this moment the raingage accumulators were reset to zero and monitoring control was returned to the WAIT mode. To avoid confusion in sample identification, the sample numbers corresponding to each automatic sampler were preserved until the telemetry system was shut down or the individual sites were reset. An entry was made into the table of contents on the data disk which identified the event just completed by its start date, start time, and number of records.

Rating Curves

Mattis Avenue Basins and Micro-Basin--

Figure 3.2 shows the rating curves for the three free-overfall sites, the Mattis Avenue basins and the micro-basin, as generated using the Manning equation. This was done after it was ascertained that the bubbler

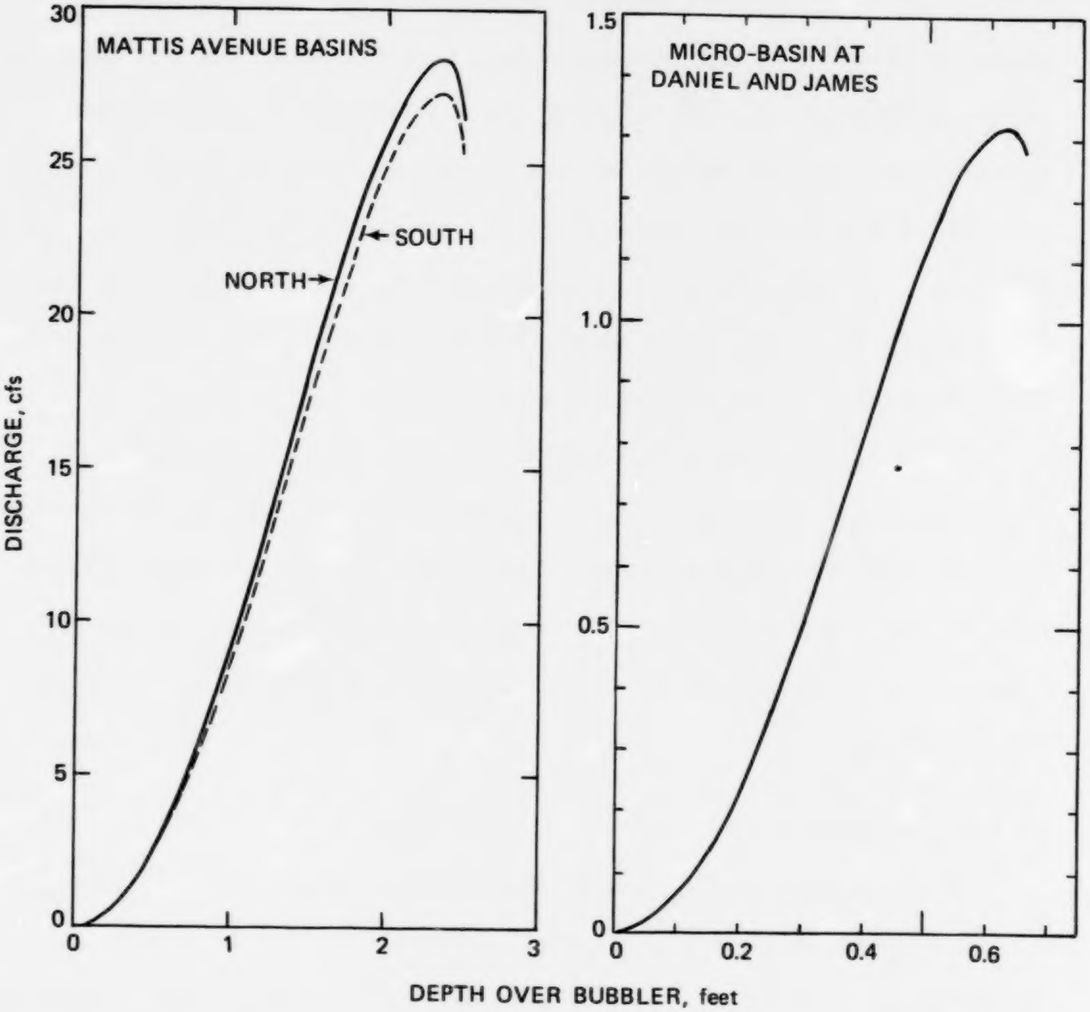

Figure 3.2 Discharge rating curves - Mattis basins and micro-basin

orifices were placed far enough upstream of the free-overfalls to avoid the effects of the critical flow and the associated hydraulic drop in depth created by the overfall. In both the Mattis basins, the bubbler orifices were placed about ten feet upstream of the overfall. At the maximum discharge of about 28 cfs, a critical depth of 1.85 feet was assumed to be generated about six feet upstream of the overfall (Henderson[10]). This left about a four foot length of pipe between the orifice and the nearest location of the hydraulic drop, which at this particular discharge, should have been more than enough to minimize the effects of the backwater profile generated by the drop. Lower discharges generated a greater length over which the surface profile effects might damp out.

At the micro-basin an 8-inch concrete pipe was cantilevered out into the manhole from the curb inlet. The bubbler orifice was placed about two feet from the free overfall. The probability that the backwater profile affected the depth over the bubbler was higher here than at the Mattis Avenue sites, but was assumed to be insignificant compared to the potential for bubbler error.

John Street Basins--

The asymmetric flumes used for flow measurement on the two John Street basins were conceptualized and tested by Wenzel[9] of the University of Illinois. This device was very attractive for several reasons. First, the outlet reaches for the two basins have mild slopes, so that a downstream control section would tend to generate a gradually varying backwater slope upstream (the importance of which will be discussed shortly). The device itself could be fabricated in-house very easily and economically. The results of tests by Dr. Wenzel were also very encouraging. Finally, Dr.

Wenzel agreed to lend his expertise in developing the constriction geometry, which was slightly different from the asymmetrical device he had tested. The theory supporting the use of these devices follows.

The principle of conservation of energy may be utilized to determine the discharge through a conduit of varying cross sections both for open channel and full flow if a hydrostatic pressure distribution exists at the measuring point s, the flow is essentially steady, the bed slope is small, and one dimensional modeling of the flow is sufficient. If the measuring point upstream is denoted as section 1, and the measuring point in the flume as section 2, we can write Bernoulli's equation as:

$$y_1 + \alpha_1 \frac{Q^2}{2gA_1^{\,2}} + Z_1 = y_2 + \alpha_2 \frac{Q^2}{2gA_2^{\,2}} + Z_2 + h_L$$

where y = depth
A = cross-sectional flow area
g = gravity
Q = discharge
Z = elevation w.r.t. some datum
h_L = energy loss between the two sections
α = kinetic energy correction factor

The purpose of the control section is to generate critical depth in the flume. In a situation involving a small slope, a backwater curve is forced upstream so that critical depth and velocity are achieved in the flume. Since only one critical depth exists for a given discharge and slope and geometry, a rating curve between the two sections may be developed by the procedure which follows.

For open channel flow:

1. Assume a critical depth, Y_2
2. Determine the cross-sectional flow area, A_2, and surface width, B_2.

3. Solve for discharge, Q, as

$$Q = \sqrt{g\;\frac{A_2}{B_2}}$$

4. Rearrange Bernoulli's equation and use the above values to find

$$y_1 + \alpha_1 \frac{Q^2}{2gA_1^{\,2}} = y_2 + \alpha_2 \frac{Q^2}{2gA_2^{\,2}} + Z_2 - Z_1 + h_L$$

where only the left side of the equation, which is a function of y_1, and the head losses are yet to be determined. The head losses may be represented as

$$h_L = K_e\left(\frac{Q^2}{2gA_1^{\,2}} - \frac{Q^2}{2gA_1^{\,2}}\right) + \int_0^L S_f\,dx$$

where K_e = entrance loss coefficient

S_f = local friction slope

L = distance between sections 1 & 2

The friction losses (S_f) are evaluated separately for the three regions, region one being the length from section two upstream to the transition, region two being the length of the transition, and region three being the length from the transition upstream to section one. The Darcy-Weisbach equation is used. Now, denoting the total friction loss as LS_f, and substituting for h_L,

$$y_1 + (\alpha_1 + K_e)\frac{Q^2}{2gA_1^{\,2}} = y_2 + (\alpha_2 + K_e)\frac{Q^2}{2gA_2^{\,2}} + Z_2 - Z_1 + LS_f$$

Now all the terms on the right side of the equation are known if it is assumed that $K_e = 0.16$ and that $\alpha_1 = \alpha_2 = 1.0$;

therefore, by trial and error, a value can be determined for y_1 which satisfies this equation.

For pipe full flow:

The values of A_1 and A_2 are constant; therefore discharge becomes a function of the pressure heads and losses, or

$$Q = \left[\frac{2g(\Delta h - h_L)}{\frac{\alpha_2}{A_2^2} - \frac{\alpha_1}{A_1^2}} \right]^{\frac{1}{2}}$$

$$\Delta h = (h_1 - h_2)$$

$$h = \frac{p}{\gamma} + Z$$

or

$$Q = Cd \left[\frac{2gA_2^2 \, \Delta h}{1 - \frac{A_2^2}{A_1^2}} \right]^{1/2}$$

and

$$Cd = \left[1 + K_e + \frac{A_2^2 \, A_1^2}{(A_1^2 - A_2^2)} \sum_{i=1}^{3} \frac{fL}{4R_h A^2} \, i \right]^{-1/2}$$

where R_h = hydraulic radius

The transition from open channel flow at both points to pipe full at both occurs over a relatively small increase in discharge, and is discussed in the literature. The rating curves developed by the above methodology are given in figure 3.3.

The one point not discussed is that as the discharge varies, the actual location of critical depth in the throat of the flume also varies. Therefore, once a depth monitoring device is installed in the flume, there is actually only one discharge for which critical flow occurs directly

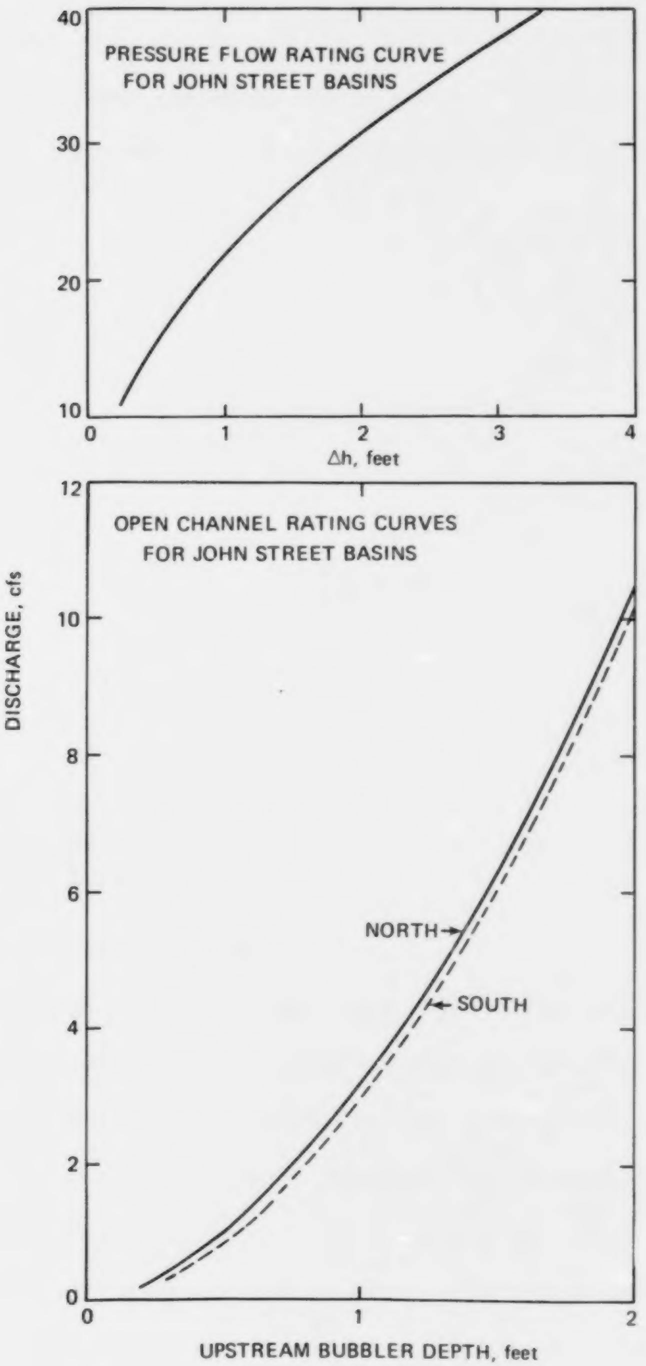

Figure 3.3 Discharge rating curves - John basins

above that point. This is why the pipe slope must be small and also why two depth sensing devices are required. The rating curve could not be used with any confidence based solely on the throat depth reading, but the gradually sloping backwater provides a reliable open channel flow.

Runoff Event Sampling

During a storm event, a sampling instruction from the system monitor to a site caused the sampler there to purge its intake line, pump a sample, and purge the intake again. The volume which could be obtained by discrete sampling was limited by the 500 ml capacity of the sampler bottles. The timing of the sampling cycle at each site was set to allow sample volumes of 450-480 ml to be collected. Overfilling a bottle could cause the accumulation of excess suspended solids, resulting in a nonrepresentative sample. Discrete samples were collected at five-minute intervals at all sites to document the change in constituent concentration throughout the storm event.

During and after storm events the sampling sites were visited by field personnel to observe performance of the samplers, collect runoff samples, and reset the system. The runoff samples were marked for identification and packed in ice for return to ISWS offices. There the record of the events were examined to aid in selection of samples to keep for analysis. Contents of the chosen sampler bottles were transferred immediately into laboratory-supplied sample bottles containing appropriate preservatives. They were then refrigerated and delivered to the IEPA laboratory along with requests for analyses. For samples in which concentrations of dissolved constituents were desired, in addition to the total concentrations normally requested, ISWS performed the filtrations as soon as possible after the samples were collected from the field. This was done to prevent any change in concentrations due to possible extended holding times before filtration in the lab.

The approach taken in selecting discrete samples for analysis was to represent the event at the site as well as possible with six to eight samples. As a general rule for each site, the samples taken first in the set and nearest to the peak runoff rate were kept. If they were separated by at least three sampling intervals, one or more of the intervening samples would also be kept. Two or more samples from the period between the peak flow and the end of the event were selected at wider time intervals, depending on the duration and flow pattern in the remainder of the event. Sample volume limitations did not permit analysis of a single discrete sample for all constituents of interest. For any event, the same analyses were requested from all samples kept from both sites in a pair of basins. The decision on analyses to be requested for samples was based on the type of event, the condition of the samples, the expectation of the runoff quality from the basins, and the requests for analysis from previous storms. Occasionally some of the remaining samples were kept, and sometimes combined, for analysis of constituents not included in the routine sampling.

The proposal for this project called for discrete sampling early in the project to be gradually replaced with composite sampling. Discrete sampling was continued throughout 1980. This was done for the following reasons:

1. Automatic collection of composite samples with the Sigmamotor samplers assumed that equal volumes of sample would be withdrawn from the flow at each signal to the sampler. It was found that

the actual sample volumes could vary by 10 to 20 percent throughout the duration of an event. A partially clogged sampler intake could cause even larger variability.

2. Manual compositing from discrete samples was an alternative but was not used early in the project due to delays in receiving a reliable flow splitting device. The small sample size (450-500 ml) made this procedure impractical.
3. Model calibration needs dictated that discrete sampling be performed for a large number of runoff events for each site. Q-ILLUDAS models the washoff of street load for one-minute increments during a storm, so it can simulate rapidly changing concentrations of runoff constituents in an event. To calibrate the model on each basin, many events were needed for which concentration data for the constituents had been determined for several observation times. Simulated concentrations were compared to those observed, and simulated and observed washoff loads were subsequently calculated.

Flow-weighted composite sampling was performed for all but a few events in 1981. The NURP consultants advocated this approach in order to hold down laboratory costs and increase the number of events covered. During an event the monitoring program calculated the incremental runoff volumes and updated the total runoff volumes for all sites each minute. Every time a volume of flow specific to a site passed the monitoring point, an instruction was sent out to the automatic sampler to collect about 450 ml of runoff. All samples at one site, up to a maximum of 40, were collected in a single container. The total sample volume was considered with the number of subsamples as a rough check of the consistency of subsample volume collection. The total sample was then split into fractions of appropriate size for various laboratory bottles, to allow analysis for all significant constituents.

Fallout Sampling

Atmospheric fallout sampling was performed at sites 1, 2, and 4. Separate wet and dry fallout samples were collected in plastic buckets placed in the device described earlier. In April 1980, bulk precipitation collectors were added to the sites. These held unprotected sample buckets which collected both dry and wet fallout in one container as long as they were exposed. After storm events, these samples were gathered at the same time as the runoff samples and transported without treatment to the laboratory where they were analyzed for many of the same constituents as the runoff samples.

Street Dirt Sampling

Experimental Design--

On six occasions between September 1979 and July 1981, large numbers of individual samples of street dirt were collected from all city blocks in the study basins. The purpose of the sampling efforts was to determine the characteristic magnitude, distribution, and variability of load on the street in each basin. These data showed a very uneven distribution of soil in the basins. The expected relationships between soil load and street type and condition were weak or inconsistent. A tendency for streets in poor condition to be more heavily loaded was found but was not strong enough to be useful in predicting loads. Large differences in average load were observed between streets. These differences were significant, ruling out a random sampling program that ignored street boundaries. The streets also varied in the amount of local uniformity which determines the sampling error and the number of samples required. Since the most uniform grouping of the data was by street, the street was adopted as the smallest subdivision of the basin for the sampling program. It was determined that the total number of samples, and thus the representativeness of the sampling effort, could be increased if the streets in a basin were grouped according to similarity in variability of load. The samples from each block of a street in a group could then be combined with samples from the other streets in the same group, resulting in a large representative sample of street dirt from the whole group.

Based on these observations the following procedure was used in constructing the production sampling program:

1. Estimates of sampling error were made for each street based on the range of values observed in the experimental design data.
2. Streets with similar error values were grouped together. Each group was represented in production sampling by one gross sample made up of subsamples from some blocks of every street in the group.
3. The number of subsamples that could be collected by a reasonable level of effort on a sampling day, with a specific number of vacuum tank cleanouts, was estimated and the total proportioned among the groups. The frequencies of subsample scheduling in the groups ranged from 0.5 to 1.5 subsamples per block. This depended on the magnitude of the expected load and variability for the group as determined from the analysis of the experimental design data.

During the early production sampling, split samples were obtained for selected groups and extra individual samples were collected on several streets. This was done to provide additional information for calculation of their sampling error and to supply justification for the transfer of any street from one group to another. Based on this sampling, Ridgeway Avenue in the John North basin was transferred twice in the first month of sampling, first from the low variability group to the medium, then from the medium group to the high. Frequencies of subsampling also were changed as the sampling program proceeded and the field crew became more proficient.

Figures 3.4-3.7 identify the streets by name in each basin; the groupings of streets for production sampling are discussed below. For the Mattis North basin, one large sample consisting of eight subsamples from the north side of Springfield Avenue and eight more from the south side was collected. In the Mattis South basin, three samples were collected: one from Mattis Avenue consisting of eight subsamples from each side of the street; one from John Street, made up of two subsamples; and one from Henry Street, made up of two subsamples. For the John North basin, three variability groups were defined. The streets in the low group were Edwin and Willis; those in the medium group were Healey, James, Chicago, and McKinley; and those in the high group were Green, John, and Ridgeway. Twelve subsamples each made up the samples from the high and medium groups, and four subsamples went into the sample for the low group. In the John South basin there were two variability groups plus two areas which received special attention. Two subsamples were taken from the micro-basin and two subsamples were taken from the block of James between William and Charles. The rest of Daniel and James Streets made up the high variability

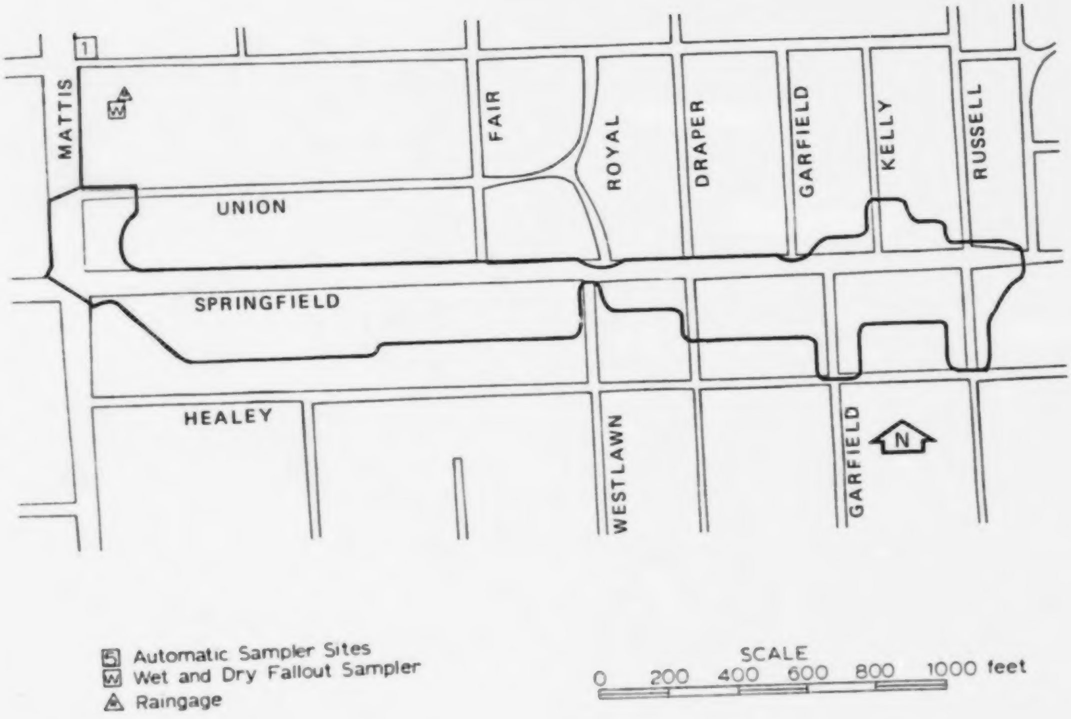
1
MATTIS
W
FAIR
ROYAL
DRAPER
GARFIELD
KELLY
RUSSELL
UNION
SPRINGFIELD
HEALEY
WESTLAWN
GARFIELD
N
5 Automatic Sampler Sites
W Wet and Dry Fallout Sampler
Raingage
SCALE
0 200 400 600 800 1000 feet

Figure 3.4 Mattis North basin - street identification

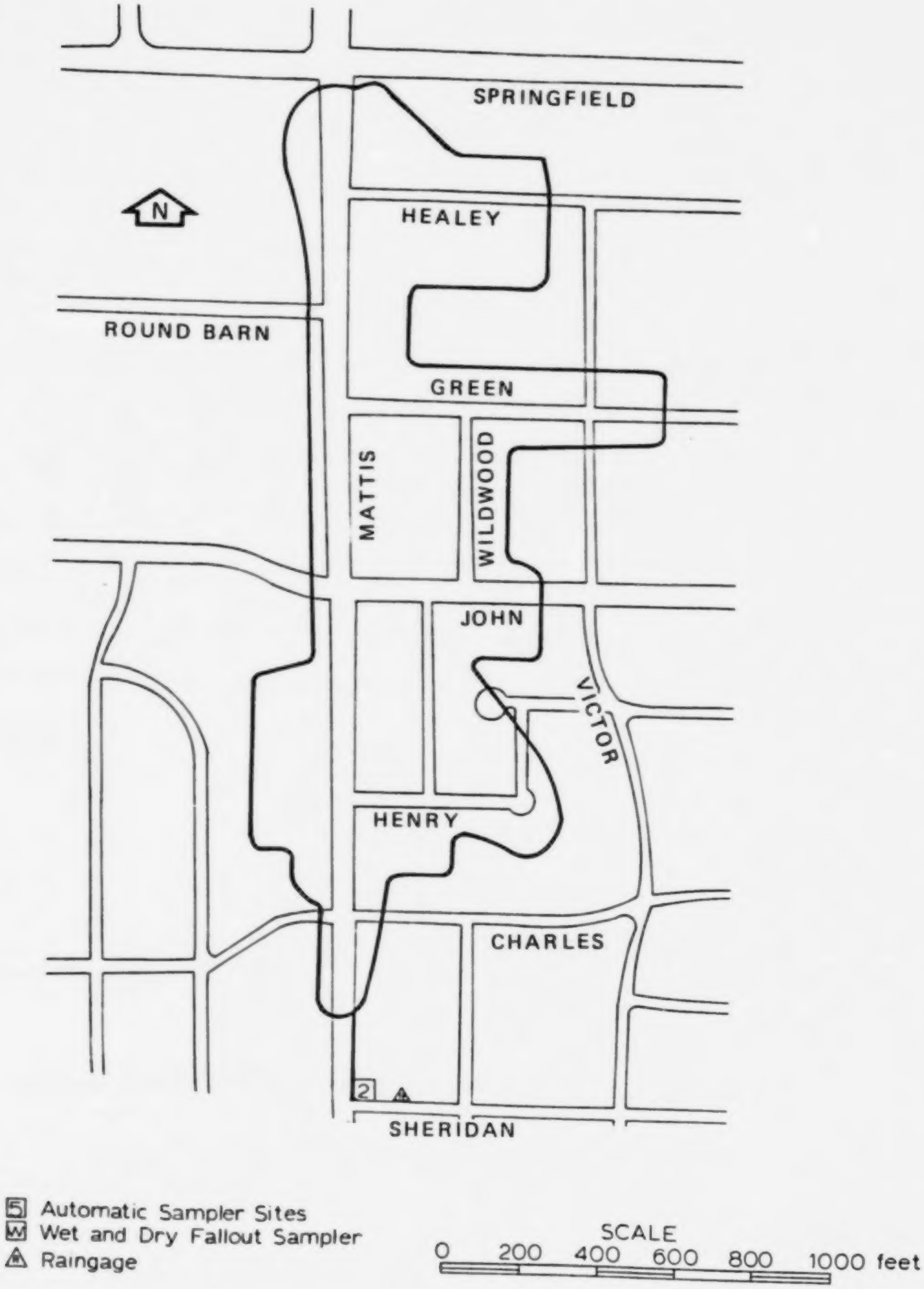
SPRINGFIELD
N
HEALEY
ROUND BARN
GREEN
MATTIS
WILDWOOD
JOHN
VICTOR
HENRY
CHARLES
2
SHERIDAN
5 Automatic Sampler Sites
W Wet and Dry Fallout Sampler
Raingage
SCALE
0 200 400 600 800 1000 feet

Figure 3.5 Mattis South basin - street identification

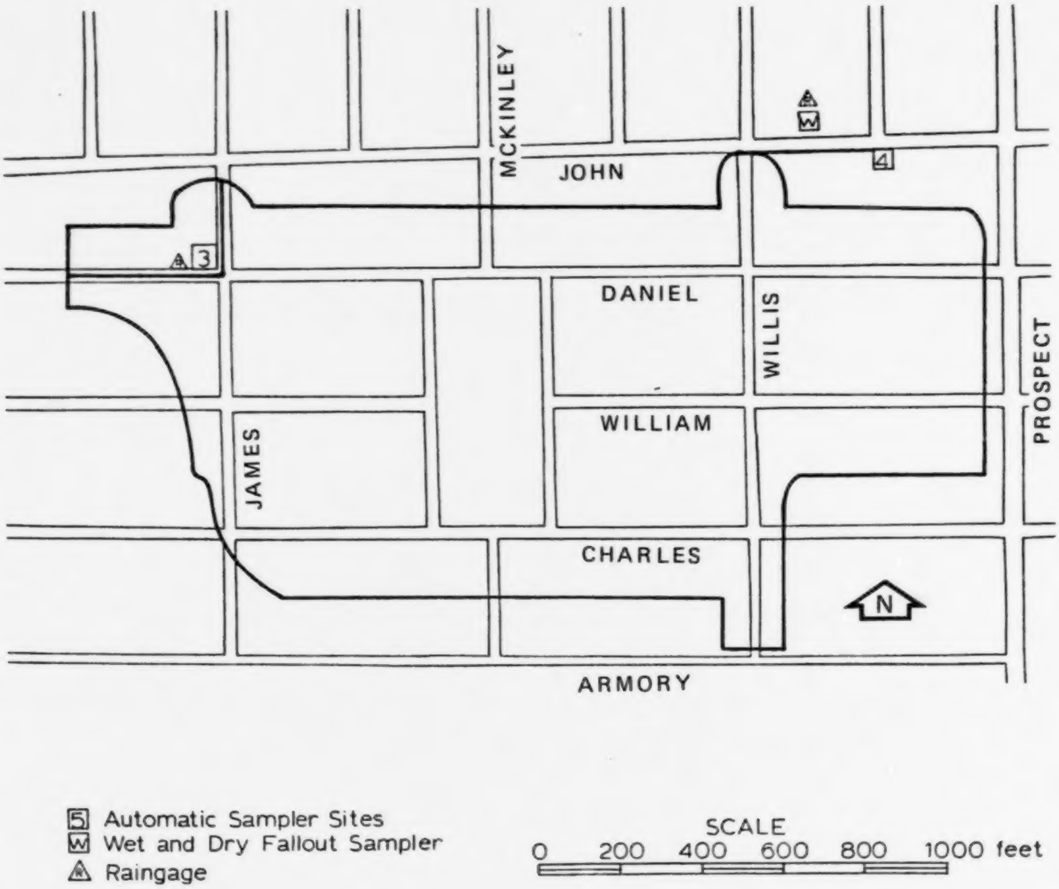
MCKINLEY
JOHN
4
W
3
DANIEL
WILLIS
PROSPECT
WILLIAM
JAMES
CHARLES
N
ARMORY
5 Automatic Sampler Sites
W Wet and Dry Fallout Sampler
Raingage
SCALE
0 200 400 600 800 1000 feet

Figure 3.6 John South basin - street identification

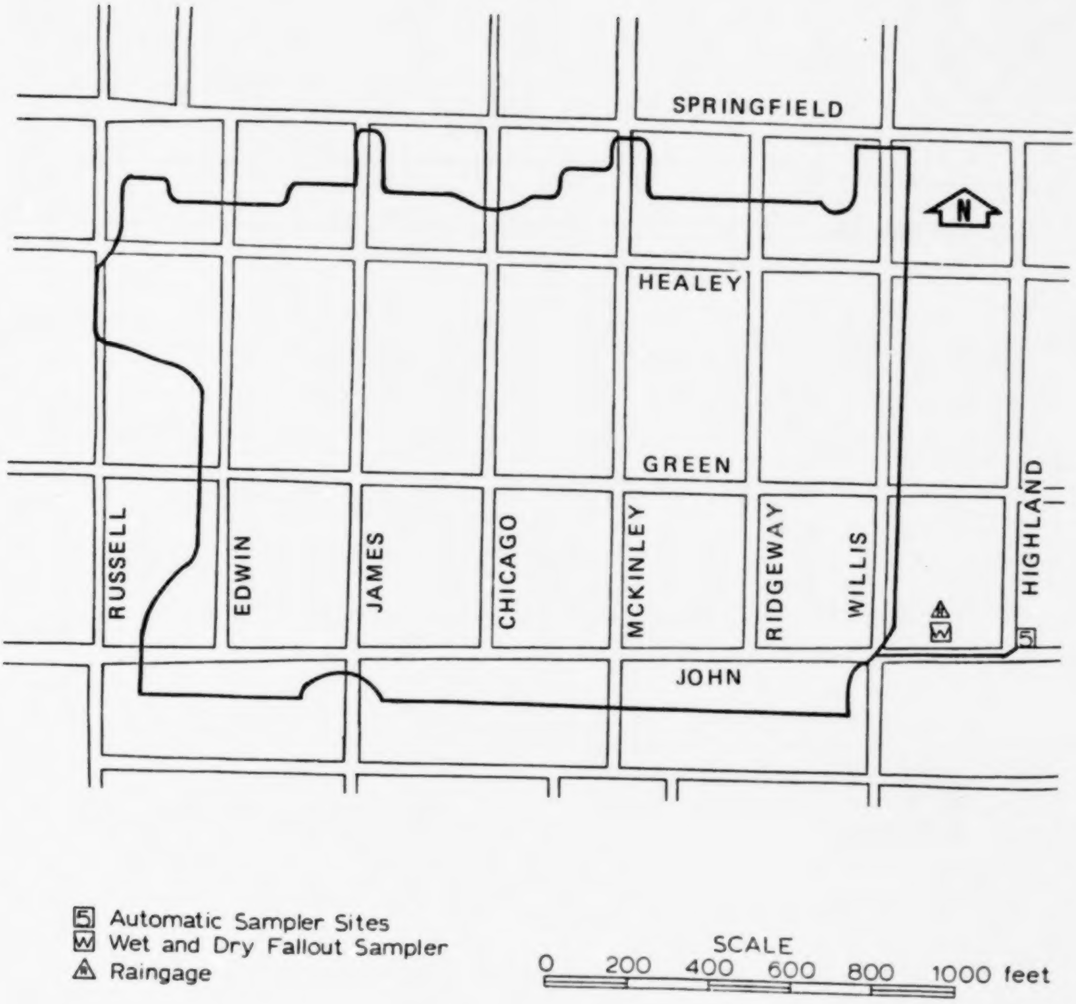
SPRINGFIELD
N
HEALEY
GREEN
JOHN
RUSSELL
EDWIN
JAMES
CHICAGO
MCKINLEY
RIDGEWAY
WILLIS
HIGHLAND
5
W
5 Automatic Sampler Sites
W Wet and Dry Fallout Sampler
Raingage
SCALE
0 200 400 600 800 1000 feet

Figure 3.7 John North basin - street identification

group, and eight subsamples were taken to represent its load. The medium variability group was comprised of Charles, Willis, William, and McKinley Streets, with 14 subsamples going into its sample.

Production Sampling--

From May 5, 1980, street dirt production sampling for total street load calculation was performed twice per week in each basin if rain did not interfere. The field crew customarily sampled the John North and Mattis South basins one day and the John South and Mattis North basins the next day. One sample was collected to represent the load on a group of streets; the sample was made up of subsamples taken from numerous locations on all the streets of a group. A subsample consisted of three passes of the vacuum intake across a street from curb to curb, or centerline to curb across two lanes of traffic for the Mattis basins. As many as 14 subsamples were composited into one sample to represent a group of streets. When the proper number of subsamples had been collected, the sample was brushed out of the vacuum canister into a plastic bag which was then marked and sealed. The gross weights of the samples were determined in the office at the end of the sampling day and the results used to estimate total street loads for the day. On a day of street sweeping in a basin, the street load was determined after sweeping was completed.

In 1981, an equipment change was made to improve the collection of material from the street surface. A smaller intake was attached to the vacuum wand, decreasing the area represented by each sampling pass but increasing the effectiveness of the vacuum on the street load. A procedural change was also made in the street dirt sampling program: on days of municipal sweeping in a basin, the load on the basin was measured before and after sweeping, instead of only after sweeping as had been done in 1980. This provided better information on sweeper efficiency and on the effect of sweeping on basin load.

Particle Size Determination--

Over periods of several weeks numerous samples from each group of streets in each basin were collected. The particle size distribution of the material in every sample was determined by passing a representative portion of the sample through a set of stainless steel sieves of decreasing mesh size and measuring the amount retained on each sieve. The fractions were then combined with similar size fractions of previous samples from the same street group and held for lab determinations of constituent concentrations in the dry solids.

The first set of sieves used in particle size determinations for this project had mesh sizes as follows: 6370μ, 2000μ, 850μ, 600μ, 250μ, 106μ, 45μ, and pan. Before sieving, a sample was divided into successively smaller portions until a test sample weighing 150-200 g was obtained. This portion of the original was placed in the uppermost sieve and the entire set was clamped into the gyratory sieve shaker which was then run for two minutes. The amount of material retained on each sieve was then weighed and placed into a bag containing material of the same size from previous samples taken from the same study area. When several samples from every study area had been broken down and composited, the fractions were taken to the IEPA lab for analysis. Constituent levels in units of milligrams per kilogram (mg/kg) dry solid were determined for each composite. The constituents sought were those found frequently in runoff samples from the same areas.

Beginning in July of 1980, it was agreed by ISWS and IEPA to follow the USGS/EPA revised Technical Coordination Plan guidelines by changing to a different set of sieves for particle size analysis. The new set had mesh sizes as follows: 2000µ, 1000µ, 500µ, 250µ, 125µ, 63µ, and pan. This set was compatible with other NURP projects and the STORET format proposed by USEPA.

Sample Analysis

The set of constituents for which storm runoff samples were analyzed was taken from the list in table 3.1. This list was a combination of two sources. The first source was the list from IEPA's original proposal to USEPA for a NURP grant and was based on the general use water quality standards of the Illinois Pollution Control Board and on sampling results from the water quality management planning studies conducted by IEPA. The second source was the list of constituents recommended in the USGS/EPA Technical Coordination Plan for sampling programs to be conducted as part of NURP. The list in table 3.1 represents the maximum number of analyses that might be requested for any sample.

During the runoff sampling program some types of analyses were requested frequently while others were requested only rarely or not at all. This was due partly to the 500 ml maximum volume of the discrete samples, which was not sufficient sample for some analyses, and partly to the fact that automatic sampling is not an appropriate sample collection technique for some analyses. Only a small amount of manual sampling was done, and that was in equipment evaluation rather than true runoff quality data collection. Automatic collection of single discrete samples and analysis for only part of the list of possible constituents was emphasized

TABLE 3.1. Maximum Constituent List for Stormwater and Street Dirt Samples

Total Suspended Solids	
Particle Size Determination	
Total Dissolved Solids	
pH	
Specific Conductance	
Nitrate plus Nitrite (as N)	Dissolved, Total
Ammonia Nitrogen (as N)	Dissolved, Total
Kjeldahl Nitrogen (as N)	Dissolved, Total
Phosphorus (as P)	Dissolved, Total
Lead	Total
Copper	Total
Iron	Total
Chromium	Total
Cadmium	Total
Zinc	Total
Mercury	Total
Organic Carbon (as C)	Dissolved, Total
Chemical Oxygen Demand	
Biochemical Oxygen Demand	5-Day, Ultimate (20-50 Day)
Fecal Coliform Bacteria	
Fecal Streptococcal Bacteria	
Temperature	
Dissolved Oxygen	
Color	
Turbidity	
Hardness	

Other special constituents: PCBs, Pesticides, Oil and Grease since such an approach provided the most useful information for the purposes of the project. When composite samples were collected later in the project a few BOD's were run and more samples were analyzed for total and dissolved fractions. A list of the constituents which have been emphasized follows with some explanation:

1. Total Suspended Solids and Total Dissolved Solids - Actually the analyses which were run would more appropriately be termed Total Nonfilterable Residue and Total Filterable Residue, respectively. These constituents relate best to the concept of basin loads of total solids accumulating during dry periods and washing off during storms. All other constituents are considered to be functionally related to total solids load in runoff.
2. Total Metals (lead, copper, iron, chromium, cadmium, zinc) - These were metals known or highly suspected of having strong associations with urban street dirt and urban runoff quality problems.
3. Total Nutrients (Organic Carbon, Chemical Oxygen Demand, Ammonia, Nitrate-Nitrite, Kjeldahl Nitrogen, Phosphorus) - Analyses for these substances were expected to indicate quality problems in urban runoff, especially from residential areas. Other constituents which were determined occasionally included dissolved metals, dissolved nutrients, sulfate, chloride, pH, specific conductance, and total mercury.

The rest of the constituents listed in table 3.1 were requested rarely if at all. The reasons for their neglect were the relative difficulty of obtaining proper samples and uncertainty about the usefulness of the results. For example, the few requests for Biochemical Oxygen Demand determinations were partly offset by the frequency of requests for other measures of organic and chemical loadings, TOC and COD, and partly by the questionable value of the BOD test as an indicator of urban runoff pollution. Similarly, the determination of contamination of urban runoff as measured by tests for fecal bacteria seemed less crucial in dealing with separate sewer flow than with combined sewer flow.

Coordination with Laboratory--

The IEPA laboratory in Champaign performed all analytical work on samples of runoff, fallout, and street dirt from this project. Early in Phase I, meetings between ISWS and lab personnel were held to discuss the types of samples that would be collected and the analyses that were appropriate for each type. For runoff samples, the main concern was how the maximum volume of 500 ml in the automatic sampler bottles might limit the number of analyses available from any single discrete sample. The lab agreed to provide prepared sample bottles of smaller volume than is conventional so that ISWS would have more flexibility in handling samples and requesting analyses.

General rules of sample handling, preservation, holding, and transport were established, along with specific means of reporting results and accounting for samples. ISWS also provided test samples of fallout and street dirt to the lab for experimentation to determine the most appropriate analytical methods to be used on them.

DATA MANAGEMENT

Operation of the automatic data collection system under the direction of the computer program RUNOFF caused data to be written to two files on disk storage, RUNOFF.DAT and TOC.DAT. The first of these files contained raw data collected by the system during events. The file was made up of 58 character records. Each record contained 1 minute of rainfall, depth of flow, station status, and the sample number retrieved by the system during an event. Identification of the separate events was made in the second file, where the start dates, times, and the durations of events were entered. Each disk was capable of holding about 60 hours of event data.

After an event ended, the automatic data collection system was shut down while the new data on the disk were transmitted to the University of Illinois CYBER 175 computer. A program called SEND was written to enable the Heath computer to read the event information from the disk and transmit it to the CYBER. The data were permanently stored in a direct access file called RAWDAT and a companion file TOC. These files had the same format as their counterparts on the data disks. Printouts of the newly acquired one-minute data were used to assist in selection of water samples from the event to keep for analysis.

A comprehensive package of programs for data management and associated computer graphics were developed in Phase I. These were used to prepare the raw data for use in continuous simulation and in creation of event data files for individual sites. Programs READATA and MANAGE were used to separate the raw data from each event by site. Then seven files were created for each site containing arrayed values of time, precipitation, flow, and water quality constituents at one-minute intervals. The time and precipitation records were taken straight from the raw data. Flows were calculated from the depth records based on the rating curve at each site. The constituent values were set to zero initially and were updated with real values as results of analysis were returned from the laboratory.

Program MANAGE was used to create event files at user-specified start times and intervals for situations in which usable telemetered data were not available. This approach was used to generate files for the first five events recorded, before the disk data management routines were operational. It was also used in one instance when the telemetered data were lost and only the five-minute printout from the terminal and the recorder charts from the field instruments were available.

Further capabilities of MANAGE included the output of event file contents in tabular and graphical formats. Table 3.2 is an example of the tabular output of an event file created with a user-specified five-minute time step. The data in table 3.2 are in units of mg/l for most constituents. The exceptions are mercury (ug/l), specific conductance (micromhos/cm), and pH (unitless). Rainfall is entered in units of inches and discharges in cubic feet per second. All integer values in any column except time are multiplied by 10 raised to the exponent indicated at the bottom of the column to yield their true values. For example, the table value for iron corresponding to time 105 is 1290 and the exponent for the column is -2; the correct value is $1290 \times 10^{-2} = 12.9$ mg/l. Examples of the graphical outputs of MANAGE are illustrated in figures 4.1-4.6. More detailed information on MANAGE capabilities and outputs is found in Appendix II, User's Manual for Data Management Program, MANAGE.

Table 3.2 Event File from Program MANAGE

TIME	RAINFALL	DISCHARGE	TOTAL SUSPENDED SOLIDS	TOTAL DISSOLVED SOLIDS	SULFATE	CHLORIDE	AMMONIA	DISSOLVED AMMONIA	NITRITE	DISSOLVED NITRITE	KJELDAHL NITROGEN	DISSOLVED KJELDAHL NITROGEN	PHOSPHORUS	DISSOLVED PHOSPHORUS	ORGANIC CARBON	DISSOLVED ORGANIC CARBON	CHEMICAL OXYGEN DEMAND	LEAD	DISSOLVED LEAD	COPPER	DISSOLVED COPPER	IRON	DISSOLVED IRON	ZINC	DISSOLVED ZINC	CHROMIUM	DISSOLVED CHROMIUM	CADMIUM	DISSOLVED CADMIUM	MANGANESE	DISSOLVED MANGANESE	NICKEL	DISSOLVED NICKEL	MERCURY	PH	SPECIFIC CONDUCTANCE
607	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
612	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
617	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
622	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
627	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
632	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
637	0	112	1610	160	16	260	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	22
642	0	235	1120	101	E	72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	82	10
647	0	169	0	0	0	0	6	0	7	0	48	0	110	0	0	0	370	7	0	80	0	1100	0	27	0	200	0	U	0	81	0	W	0	0	0	0
652	0	89	710	90	E	62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	U	0	0	81	9
657	0	67	0	0	0	0	6	0	9	0	45	0	75	0	0	0	218	13	0	60	0	760	0	20	0	30	0	U	0	54	0	W	0	0	0	0
702	0	59	450	96	E	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	79	9
707	0	53	0	0	0	0	5	0	7	0	28	0	49	0	0	0	148	3	0	40	0	350	0	14	0	T	0	U	0	26	0	W	0	0	0	0
712	0	42	230	81	E	78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78	10
717	0	35	0	0	0	0	5	0	9	0	38	0	56	0	0	0	169	5	0	60	0	440	0	16	0	10	0	U	0	33	0	W	0	0	0	0
722	0	29	270	104	E	92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77	12
727	0	25	0	0	0	0	6	0	10	0	30	0	50	0	0	0	152	2	0	40	0	300	0	13	0	10	0	U	0	22	0	W	0	0	0	0
732	0	25	150	51	12	110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77	12
737	0	17	0	0	0	0	5	0	10	0	27	0	45	0	0	0	144	2	0	40	0	200	0	12	0	T	0	U	0	16	0	W	0	0	0	0
742	0	13	120	57	12	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	76	14
747	0	13	0	0	0	0	5	0	10	0	26	0	43	0	0	0	123	2	0	30	0	160	0	10	0	T	0	U	0	14	0	W	0	0	0	0
EXP=	-2	-1	0	0	0	-1	-1	-1	-1	-1	-1	-1	-2	-2	0	0	0	-1	-1	-3	-3	-2	-2	-2	-2	-3	-3	-3	-3	-2	-2	-2	-2	-2	-1	1

28 COMMENT RECORDS EXIST

When the results of sample analyses were returned from the laboratory to ISWS, they were sorted by site, event, and sampling sequence and stored in notebooks. As soon as the event files were created, the corresponding runoff quality data were entered as updates to the files. The notebooks were kept as backup information, but all subsequent inspection, manipulation, and analysis of the records of runoff events was done using the event files stored on the CYBER.

EXPERIMENTAL STREET SWEEPING PROGRAM

The project work plan called for municipal street sweeping of the experimental basins to start in July 1980, just before the end of Phase I. Planning meetings between ISWS and the Champaign Department of Public Works were held in June and July to establish procedures and responsibilities for the sweeping programs. Municipal sweeping of the experimental areas began July 21, 1980, and continued for the rest of the 1980 and all of the 1981 sampling seasons.

Before starting the municipal sweeping program, curbs at the study area boundaries were painted for easier identification of the turnaround points by the sweeper operator. Once this was done, city staff members experienced in route design laid out an efficient route for the operator to follow in sweeping the experimental basins. This route was drawn on a map the operator carried in the sweeper. The city also delivered leaflets written by ISWS to the basin residents to explain the activities of the municipal sweeping and street dirt sampling crews and to describe the project simply.

On a sweeping day, the entire length of curbed street in each experimental basin was swept. The city was responsible for providing the following:

1. Sweeper and operator
2. Truck (for hauling sweeper material) and driver
3. Weights of the gross load of material collected in each basin
4. Samples of sweeper contents after completing each area
5. Records of date of sweeping, time required per basin, operator and equipment identification, and truck load weights
6. Comments about conditions noted in the basins which might affect load measurements
7. Maintenance and repair records for the sweeper

The street sweeper provided by the city was a 1973 Elgin Model Pelican "S", a three-wheel mechanical sweeper with dual gutter brooms and main rotary broom. It had a sweeping path with one gutter broom of eight feet, an outside turning radius of 15 feet, and a hopper capacity of 2.5 cubic yards.

No special instructions regarding procedure were given to the operator beyond the admonition to sweep only within the basin boundaries and the requirements of measurement and observation listed above. Sweeping was to consist of a single pass of the sweeper along every curb in a basin at a speed determined by the operator to be adequate for removing the load. This was done in the expectation that it would best demonstrate the effect of an actual municipal sweeping program of the designated frequency. The determination of that effect was considered most appropriate to the primary objective of the project.

Before July 21, 1980, all four study basins had been deliberately left unswept for several weeks after a complete spring cleanup. This was done so that the fundamental characteristics of accumulation, distribution, and removal by washoff of street dirt load in each basin could be determined. Not sweeping the basins permitted the observation of the basin loads approaching steady-state conditions, where daily accumulation is balanced by daily removal due to traffic and wind. The maintenance of the unswept condition in the basin also offered the potential for the clearest identification of the effect of municipal sweeping on basin load and runoff quality. For that reason no sweeping was planned for the designated control basins during the remainder of the project except as necessary to satisfy citizen complaints, to alleviate major nuisances, or to create conditions suitable for special sampling projects related to the aims of the study.

The John North and Mattis South study areas were designated as experimental basins for the start of the sweeping program. This allowed the monitoring of unswept conditions to be continued in the John South basin, which includes the micro-basin. Equipment problems at sites 3 and 4 hampered the collection of event data during the first phase. The selection of John North and Mattis South also enabled the City to meet some obligations for bicycle path maintenance in these areas, which had been neglected through Phase I.

The first municipal street sweeping frequency selected for evaluation was twice per week. The experimental basins were swept each Monday and Thursday if nothing interfered. If rain or equipment failure prevented sweeping on a Monday, that week's schedule was shifted to Tuesday and Friday. If on subsequent days it was still impossible to sweep, the schedule shifted successively to Wednesday and Friday, Thursday and the following Monday, and finally Friday and the following Monday.

This twice-weekly sweeping program was conducted from July through October and into November, when municipal sweeping was halted for the winter. The two basins which were not being swept routinely, the control basins, had major cleanups at the end of September. All four basins were cleaned in November, just before shutdown of the system.

In 1981 runoff event monitoring began again in February. Cleanups of winter street dirt accumulation were conducted in the basins at the end of March, and in April street dirt sampling and municipal sweeping were resumed. The same basins, Mattis South and John North, were used for experimental sweeping during April and May as had been used in 1980, but the frequency of sweeping was changed to once per week. In June street sweeping was halted in the experimental basins and started in the other basins and the "experimental" and "control" designations were switched. The frequency of experimental sweeping remained at once per week. The sweeping schedule and the water quality sampling periods are depicted in figure 3.8.

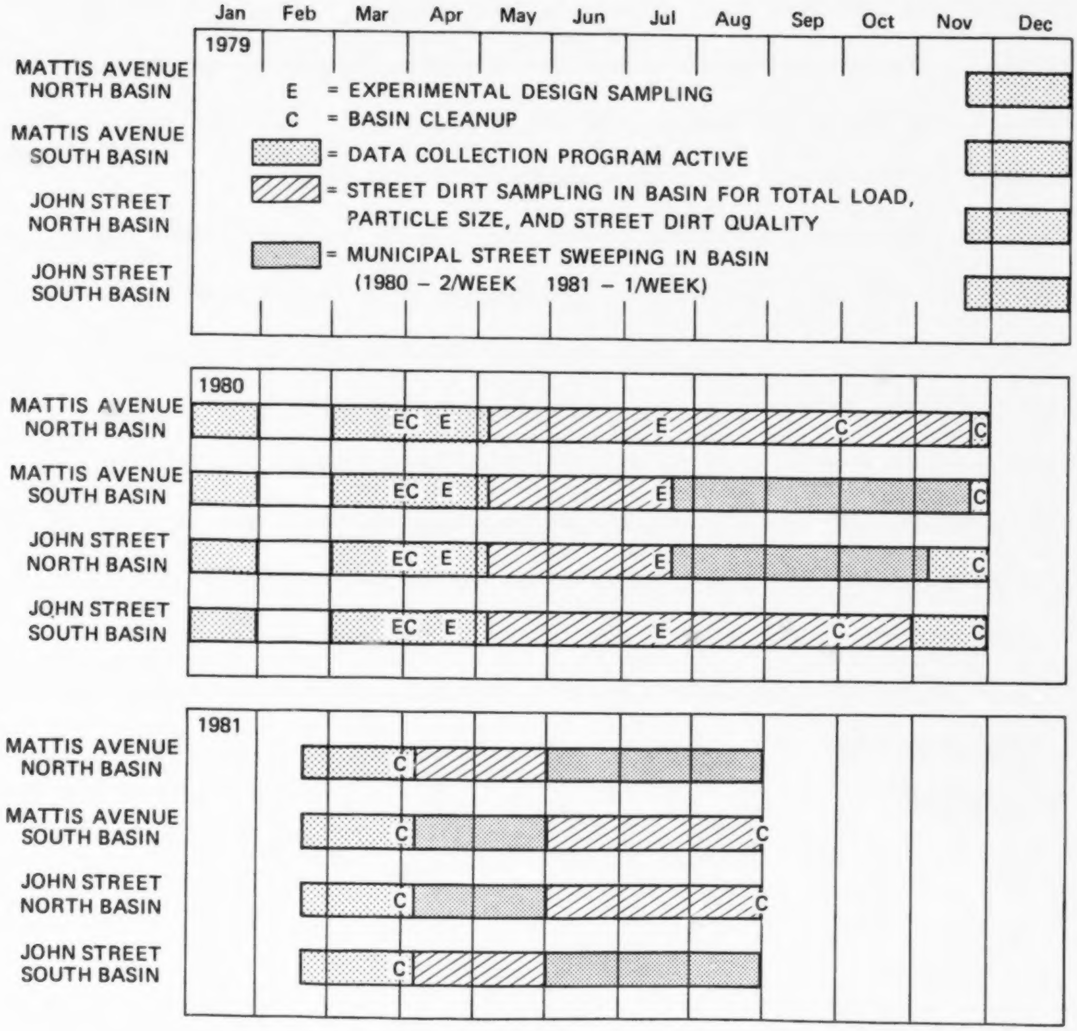

Figure 3.8 Data collection and street sweeping calendar

SECTION 4

SIMULATION

Q-ILLUDAS DESCRIPTION

Q-ILLUDAS is a quasi-continuous urban runoff quantity-quality model. It was developed by the Illinois State Water Survey and is based on their earlier Illinois Urban Drainage Area Simulator (ILLUDAS)[4] model. The model is fully continuous in its accounting of rainfall and soil moisture. It is not continuous in its simulation of pipe and stream flow, which are only simulated as precipitation occurs. Groundwater movement and thus baseflow are not simulated, and therefore dry period flows are not modeled.

The rainfall/soil moisture processor accounts for both impervious and pervious depression storage, as well as interception by canopy, and utilizes Horton's infiltration curve for soils of the four basic hydrologic groupings. All storages are assumed to be spatially distributed and are processed with a triangular storage curve. Any combination of two raingages and two soil types may be used to simulate a basin. Discrete accounting is provided for directly connected paved areas, contributing grassed areas, and grassed areas affected by impervious areas which are not directly connected (such as green belts between curbs and sidewalks). The result is a set of effective hyetographs for the three cover types.

The event simulator processes each subcatchment of the user-input branch-reach network in a downstream direction, producing both a reach hydrograph for the subcatchment and an input time series for the next downstream reach. Backwater conditions, and thus pressure flows, are not considered. If instantaneous input exceeds pipe capacity, the excess is stored at the upstream end until it can be released.

Overland flow routing may be done by either of two methods. One method uses a time-invariant concentration time from the most remote point to the inlet; the other allows a kinematic wave to form on the surface with concentration time based on the mean depth on the overland flow plane. Reach routing is a simple storage routing technique which determines flow-through time as a function of inlet peak and full flow discharges.

Urban runoff water quality is simulated as a function of particulate washoff in the basin. A series of work equations determines how much particulate load may be entrained into surface flow each minute, or how much must settle out of the surface flow. These work equations are a function of the time-invariant physical characteristics of the basins, the temporally distributed rainfall/runoff data generated by the rainfall processing, the surface storage of particulates, and the suspended load. The model algorithms created for simulating these equations are the direct result of the second goal stated in Section 1. The user may specify up to five particle sizes and must provide initial loads, accumulation rates, and densities. Information obtained as a result of the first goal of this study was used to define the accumulation function parameters in the simulation. Constituent concentrations for desired pollutants are determined by adding the washoff concentration, determined by applying user-specified potency factors (grams of constituent per gram of sediment) for each of the particle size groups simulated, to the rainfall concentration supplied by the user.

Model details and a user's manual are presented in Appendices I and II.

TABLE 4.1. Observed and Simulated Storm Parameters

John South Basin

Event date	Total rain (in)	5-min rain (in)	Observed Data Peak (cfs)	 R.C. (in/in)	Simulated Data Peak (cfs)	 R.C. (in/in)
3/16/80	0.88	0.11	5.24	0.32	5.09*	0.17
5/17/80	0.46	0.14	6.32	0.23	5.08*	0.13
6/28/80	0.25	0.10	4.14	0.15	4.76	0.11
7/27/80	0.86	0.13	6.55	0.13	5.26*	0.15
9/16/80	0.82	0.08	4.15	0.15	4.16	0.15
10/1/80	0.11	0.03	1.36	0.16	1.48	0.16
John North Basin						
3/16/80	0.88	0.11	6.74	0.29	7.86	0.30
5/17/80	0.46	0.14	8.16	0.21	8.49	0.14
6/28/80	0.25	0.10	6.82	0.16	6.26	0.11
7/27/80	0.86	0.13	11.49	0.20	11.32	0.16
9/16/80	0.82	0.08	7.22	0.16	5.53	0.16
10/1/80	0.11	0.03	1.86	0.23	1.89	0.17

*indicates surcharged simulation

HYDROLOGIC VERIFICATION

As a part of the hydrology simulation, each event for each basin has been analyzed to generate total event rainfall, event five-minute maximum rainfall, observed peak, observed runoff volume, observed runoff coefficient, simulated peak, and runoff coefficient. Table 4.1 is a comparison of observed and generated data for six events on the John Street basins, corresponding to the plotted hydrographs and hyetographs in figures 4.1 through 4.6.

The results shown on the table and plots represent a nine-month continuous simulation of each basin. The simulation is quite good, considering that the proximity of the two raingages used with respect to the size of the two basins may not generate sufficient north-south definition of storm tracking and do not show a north-south variation in rainfall.

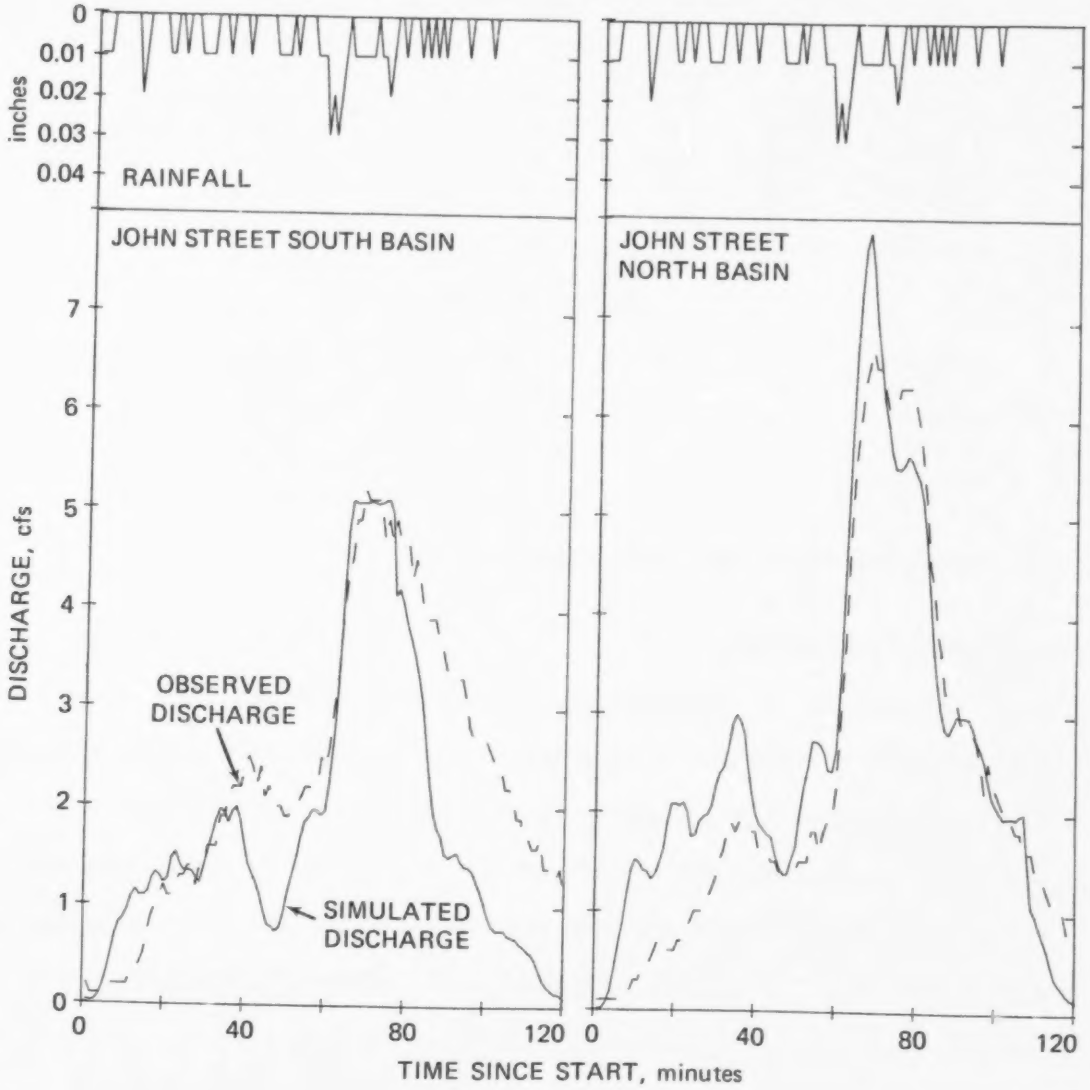

Figure 4.1 Observed and simulated runoff flows - John basins - March 16, 1980

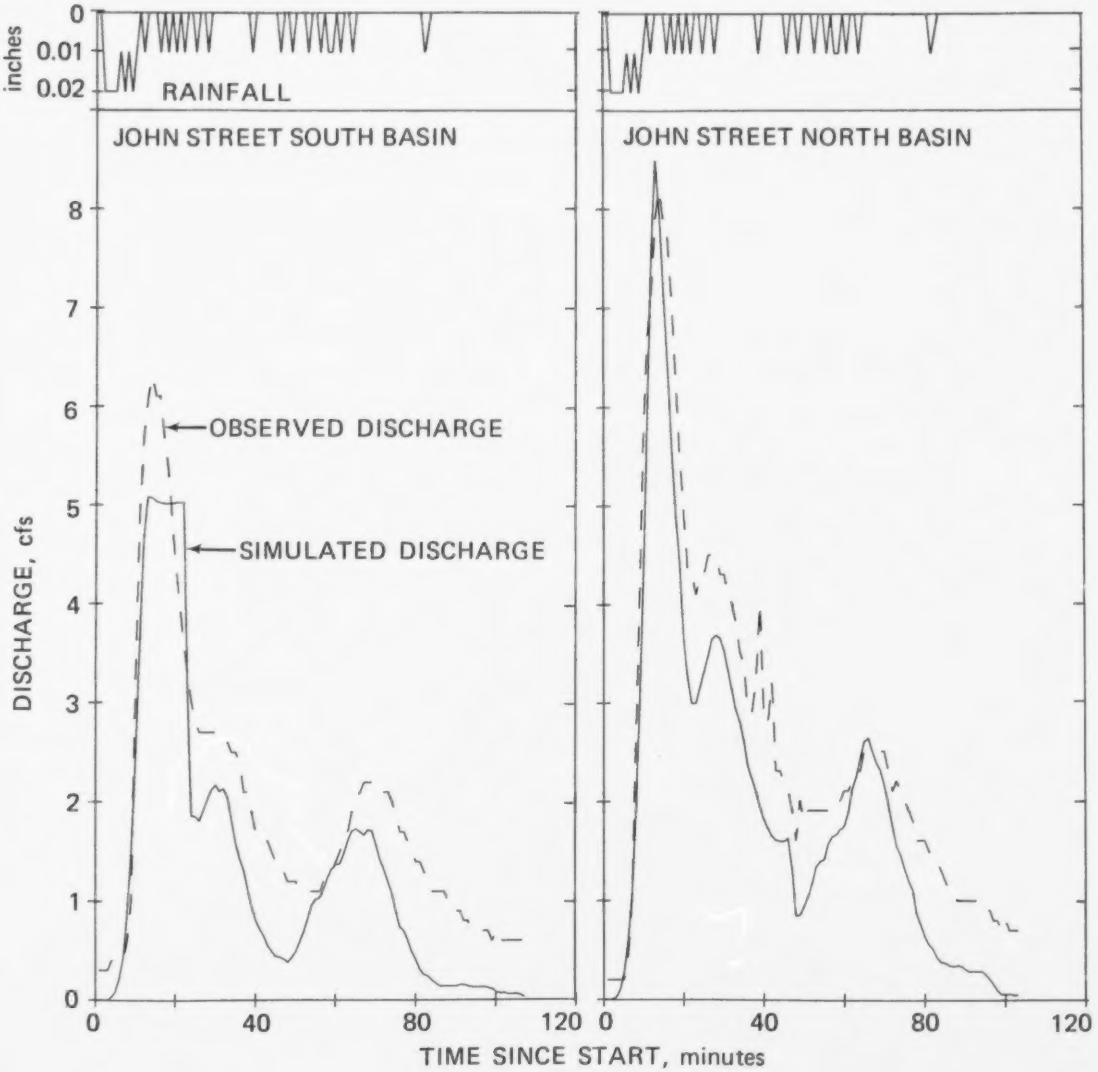

Figure 4.2 Observed and simulated runoff flows - John basins - May 17, 1980

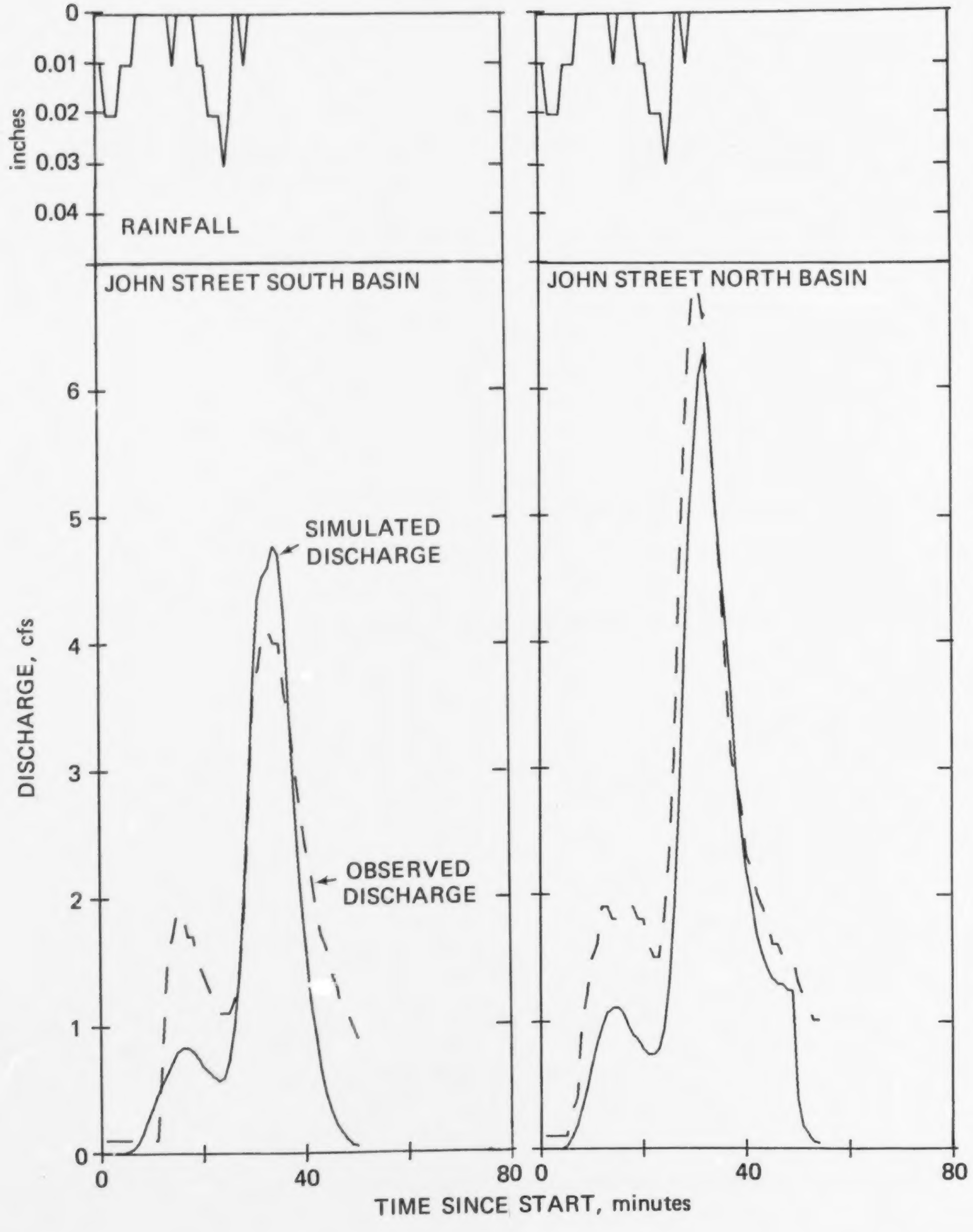

Figure 4.3 Observed and simulated runoff flows - John basins - June 28, 1980

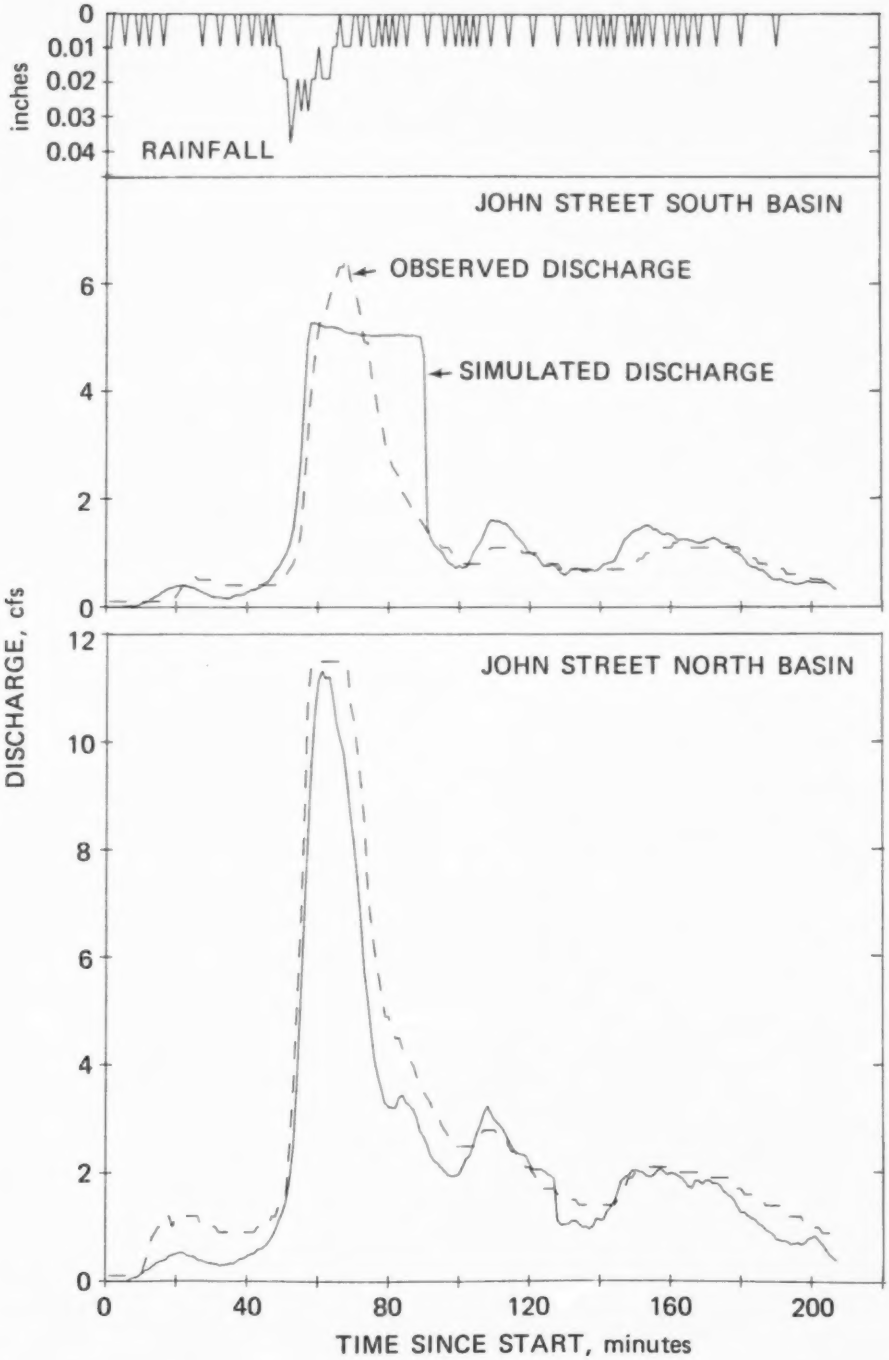

Figure 4.4 Observed and simulated runoff flows - John basins - July 27, 1980

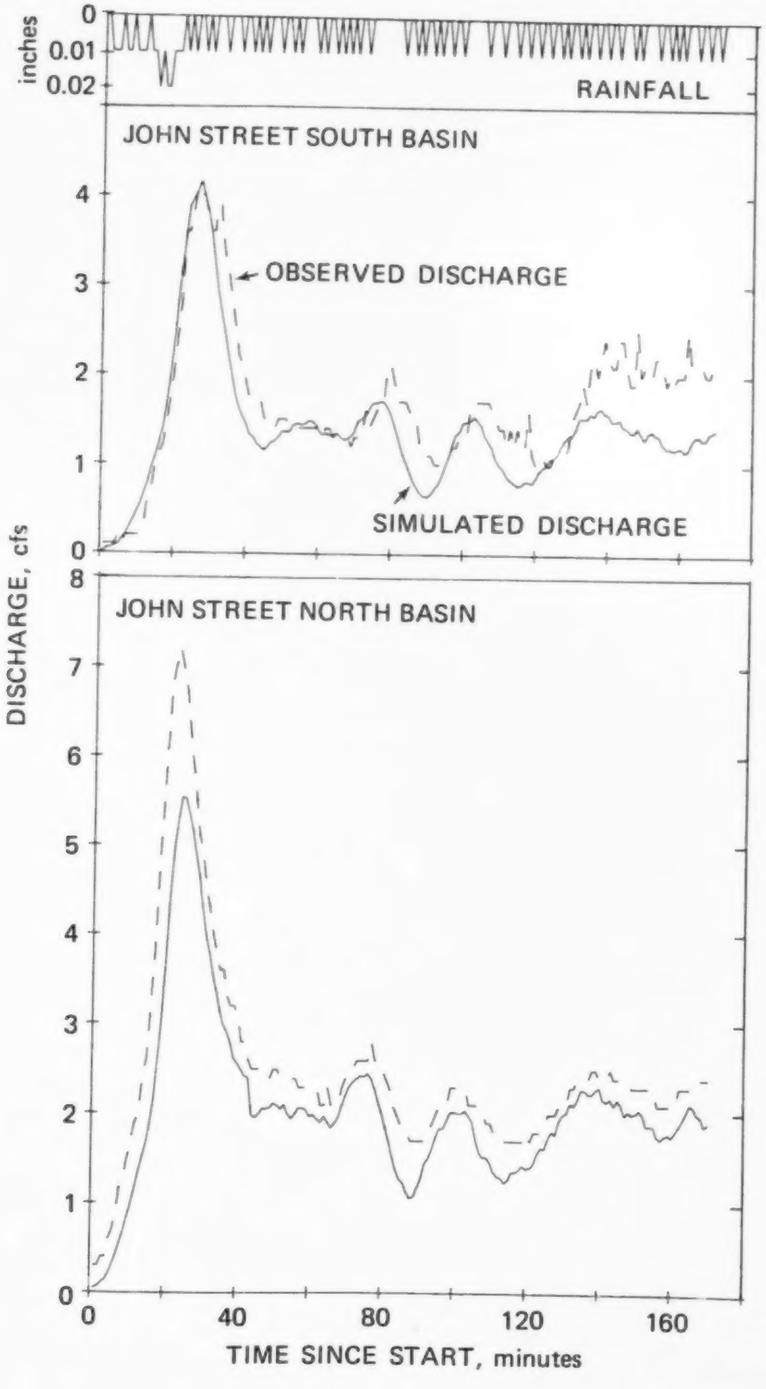

Figure 4.5 Observed and simulated runoff flows - John basins - Sept. 16, 1980

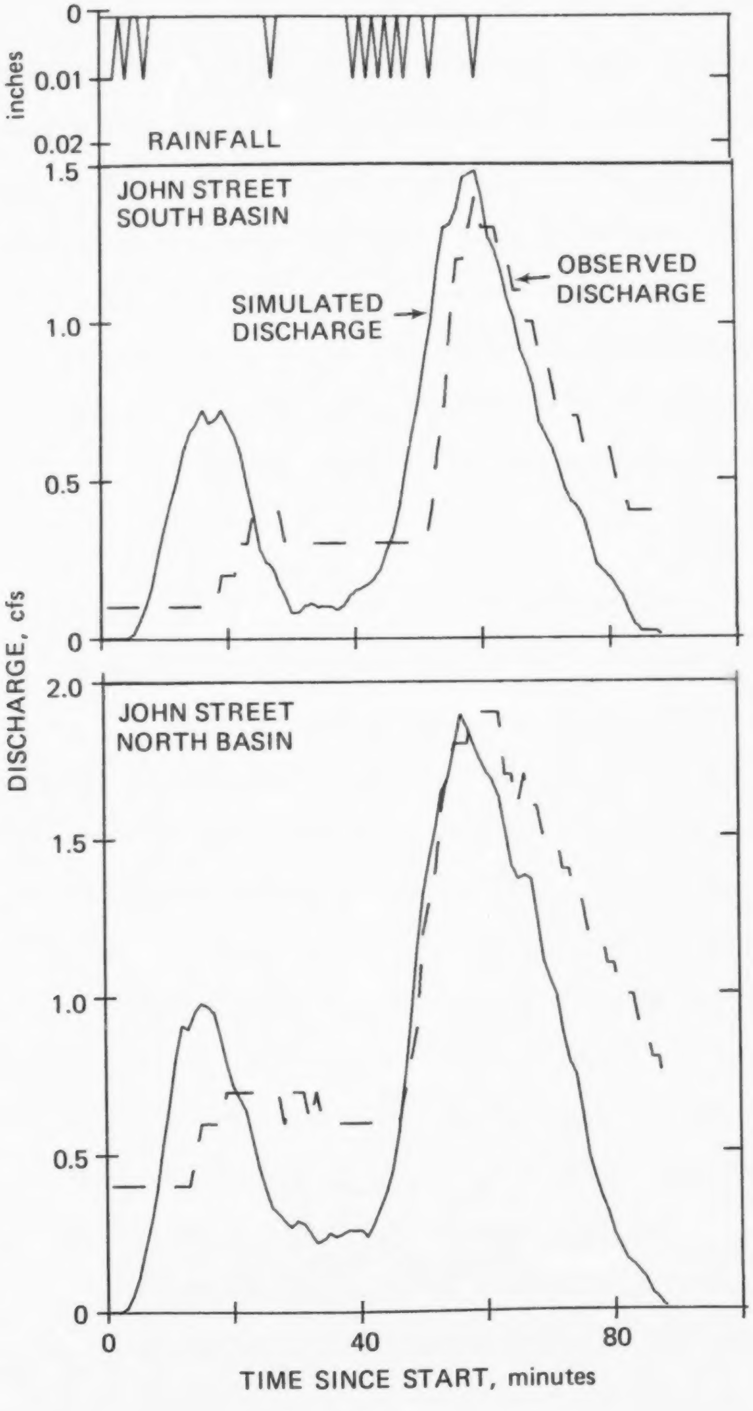

Figure 4.6 Observed and simulated runoff flows - John basins - October 1, 1980

In order to be confident that the modeling of water quality concentrations is truly representative of what is actually happening on the water shed, events such as those shown here were used as a final calibration of the pollutant potency factors. These events demonstrate similarity in observed and simulated hydrograph peaks, volumes, runoff coefficients, and overall shapes. This implies that the point-to-area uniform rainfall distribution assumed in such models is more reliable for these events than in events where a large degree of temporal distribution may be expected, such as scattered thunderstorms.

QUALITY VERIFICATION

The simulation results obtained using Q-ILLUDAS range from very good for the hydrologic modeling to fairly good for the water quality modeling. The simulated hydrographs and corresponding observed hydrographs illustrated in figures 4.1 through 4.6 show that the model does indeed do a good job modeling the rainfall-runoff relationship for urban areas. Some of the more pertinent basin characteristics and parameters used in the simulation are shown in table 4.2. In the table, CPA represents directly connected impervious areas such as streets. SPA represents those impervious areas from which the runoff must traverse some length of pervious surface enroute to an inlet, such as rooftops and sidewalks. CGA is the pervious area deemed significant in its contribution to urban storm runoff, such as front yards and parkways. ET storage is the maximum portion of the groundwater storage available to satisfy evapotranspiration potential, and GW storage is the storage available when field capacity of the soil is exceeded, and moves off both vertically via percolation and downslope as subsurface gravity flow.

Using the John South basin as an example, table 4.3 shows the data by particle size needed to simulate total dissolved solids (TDS), total suspended solids (TSS), total Kjeldahl-nitrogen (K-N), total phosphorus (P), total iron (Fe), and total lead (Pb). Table 4.4 shows the nine-month simulated total solids washoff from the two John Street basins. Precipitation data are available for the other three months, but were not used for two reasons; first, municipal street cleaning cannot be done at regular intervals in the midwestern United States during these months and second, the model does not simulate snowpack or snowfall related events. In this latter case, ignoring precipitation as snow or the runoff volume contributed by existing snow cover can generate extremely erroneous data. Figures 4.7 and 4.8 show the model results for the event of March 16, 1980, on the John South basin. It should be noted that since the composite pollutograph for a particular constituent is generated from up to five washoff loadographs, each of which is characterized by a discrete mean diameter (see table 4.3, line 1), smooth curves are not generated unless only one group is used to characterize the occurrence of the constituent. As seen in Figures 4.7 and 4.8, the model does a reasonable job of approximating the observed concentrations, with the exception of the simulation of total phosphorus. The calibration of phosphorus is poor because its occurrence in the runoff seems to shift from being related to large solids in the early portion of events to being related to very fine particles later in the event. Figure 4.9 shows a plotting of simulated event mean concentrations against the observed mean concentrations. In some cases, the first samples sent to the lab for analysis were taken after the peak concentration for a given constituent had occurred, which means the simulated data would reflect this concentration in its computation of event mean and total loads from one-minute data, whereas the data available from the sampling would not. The total expected washoff loads for the six modeled constituents are shown in table 4.5 for the John South basin.

Table 4.2. Basin Characteristics and Parameters

	Mattis North	Mattis South	John South	John North
Total Area, acres	16.7	27.6	39.2	54.5
CPA, acres	9.7	11.1	6.8	10.0
SPA, acres	0.5	3.1	5.8	7.9
CGA, acres	6.5	13.4	26.5	36.5
Impervious roughness	0.018	0.018	0.018	0.018
Impervious surface depression storage, inches	0.10	0.10	0.10	0.10
Soil type	B	B	B	B
Pervious roughness	0.05	0.05	0.05	0.05
Pervious surface depression storage, inches	0.18	0.18	0.18	0.18
ET storage, inches	2.40	2.40	2.40	2.40
GW storage, inches	1.60	1.60	1.60	1.60
Final percolation rate, (in/day)	0.15	0.15	0.15	0.15
Number of reaches modeled	9	9	15	23

Table 4.3. Sediment Characteristics for John Street South Basin

		GROUP				
		1	2	3	4	5
Mean diameter, microns		8	31	94	183	600
Density		2.65	2.65	2.65	2.65	2.65
Accumulation, kg/km/day		0.25	0.31	0.41	0.72	8.85
Impervious loss rate, % per day		7.5	7	5	4.5	4
Pervious loss rate, % per day		5.5	5.5	5	4	3
Potency factors:	TSS	0	0	0.3000	0.4500	0.8289
	TDS	0.0450	0.0675	0.075	0.2475	0.1628
	K-N	0.001	0.002	0.0018	0.0018	0.0014
	P	0	0	0	0.0030	0.0011
	Fe	0	0	0.0047	0.0038	0.0068
	Pb	0.00002	0.00020	0.00033	0.00015	0.00123

Table 4.4. Total Solids Washoffs, in Kg

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total 9 mon.	Estimated total 12 mon.
John S	1964	982	2935	2311	1315	1556	1425	1936	1495	15919	18322
John N	2982	1848	3562	3616	2546	2444	2178	3470	2356	25002	28776

Table 4.5. 1980 Constituent Production on John South, in Kg

Month	TSS	TDS	K-N	P	Fe	Pb
Mar	1473	321	6.73	1.68	10.4	0.777
Apr	688	158	3.42	0.84	4.89	0.354
May	2264	478	9.96	2.44	15.9	1.21
Jun	1724	377	7.91	1.97	12.1	0.907
Jul	948	214	4.54	1.14	6.71	0.492
Aug	1140	253	5.36	1.33	8.06	0.596
Sep	1100	233	4.83	1.20	7.70	0.585
Oct	1439	316	6.66	1.65	10.2	0.759
Nov	1126	246	5.13	1.29	7.93	0.596
9 months	11902	2596	54.54	13.54	83.89	6.276
12 months	13174	2874	60.56	15.02	92.50	6.900

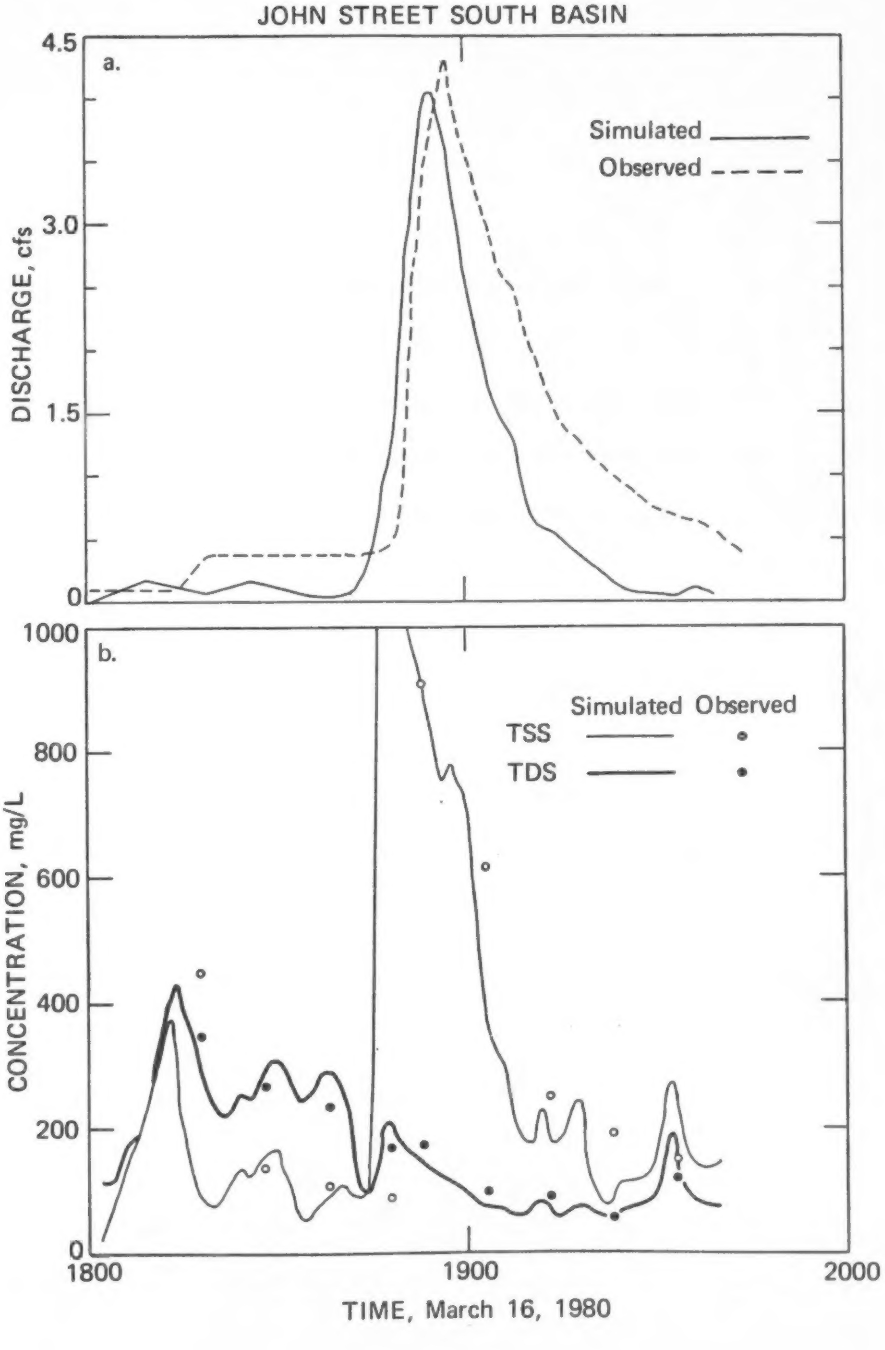

Figure 4.7 Observed and simulated runoff flow and quality - John South March 16, 1980

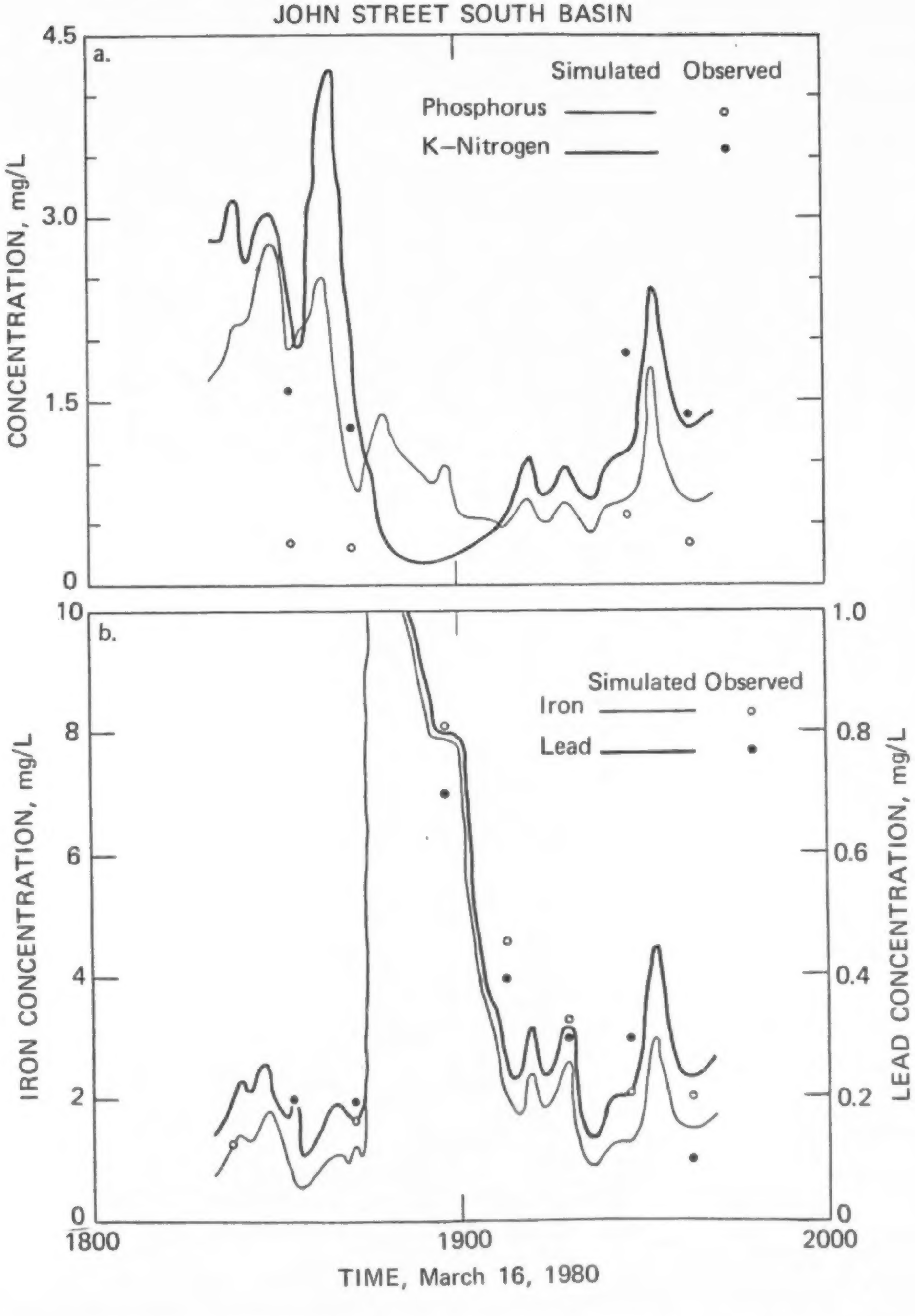

Figure 4.8 Observed and simulated runoff quality - John South - March 16, 1980

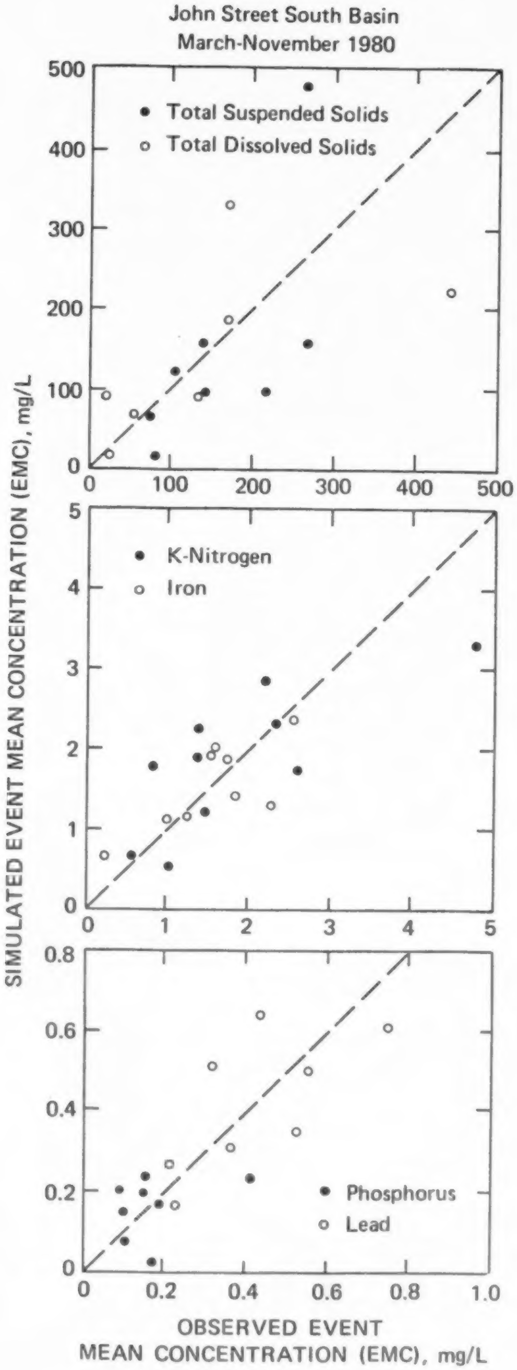

Figure 4.9 Observed vs. simulated event mean concentrations - John South March - November 1980

HYDROLOGIC SIMILARITY

The hydrologic similarity of the basin pairs was determined by simulating their response to two thirty-minute storms, one of 0.25 inch (0.0083 inch per minute) and the other 0.50 inches (0.0167 inch per minute). The resultant hydrographs are shown in figures 4.10 and 4.11. The major difference seen on the Mattis Avenue basins is that the event moves through Mattis South more quickly. This is due to the steeper overall slope with respect to Mattis North. Mattis South also shows a much steeper recession limb on the hydrographs. This is due to relatively steep surface grades at the upper end of the basin which in turn generate a low time of concentration for surface runoff reaching the inlets.

The hydrographs resulting from 0.25 inch of rain on the John Street basins show a very high degree of similarity. The more intense rainfall on the John South basin, however, shows that a hydraulic bottleneck exists near the basin outlet which is surcharging flows greater than about 5.1 cfs. Inspection of the observed hydrograph on John South for July 27, 1980, shows that the discharge does in fact reach higher rates, due to the pressure head generated upstream of the problem area. As seen in figure 4.12, the observed discharge does cease to increase momentarily at about 5.5 cfs while the pressure head is being developed.

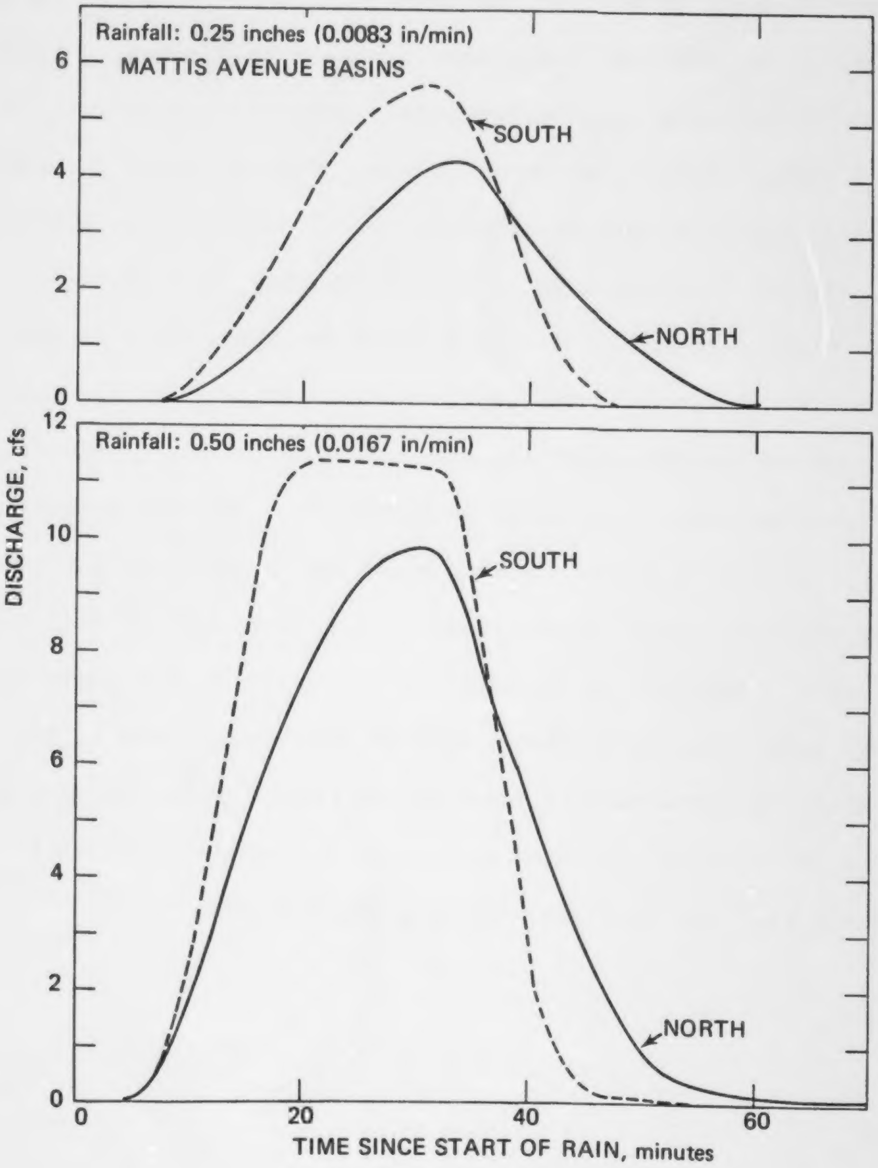

Figure 4.10 Hydrologic similarity - Mattis basins

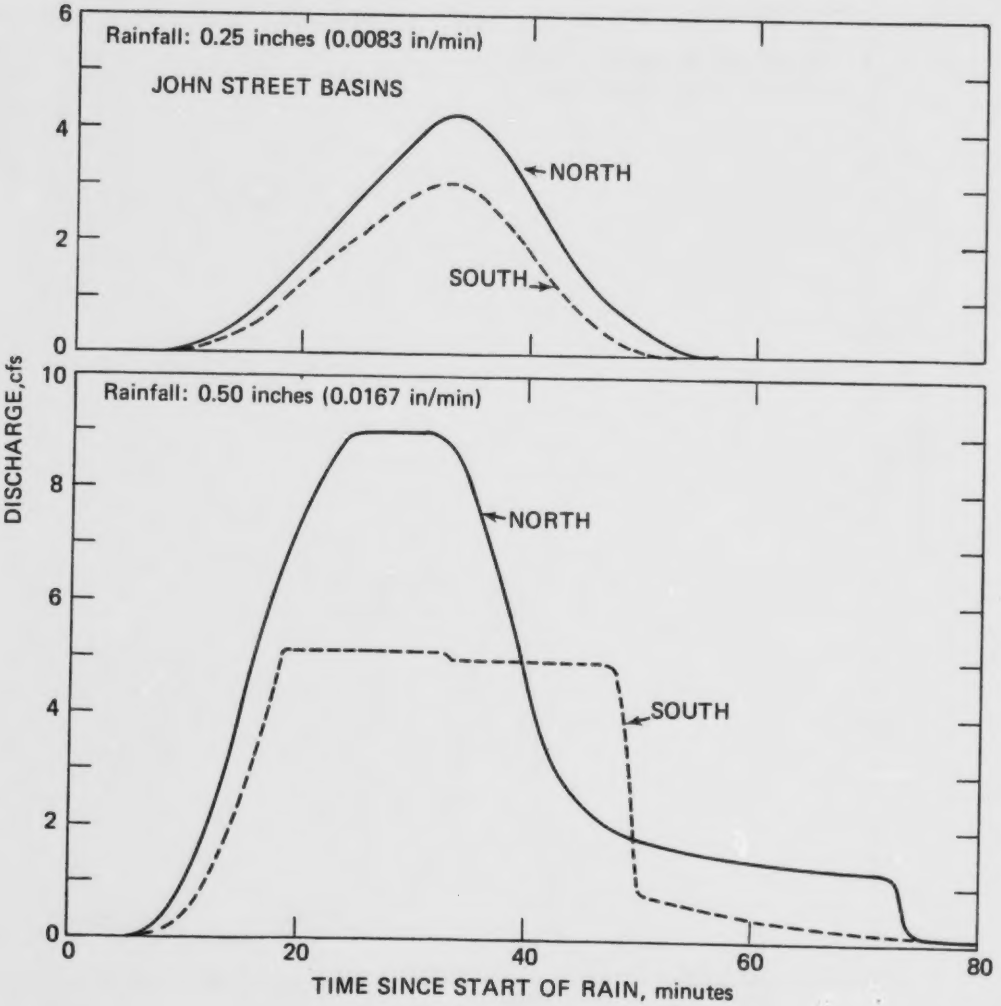

Figure 4.11 Hydrologic similarity - John basins

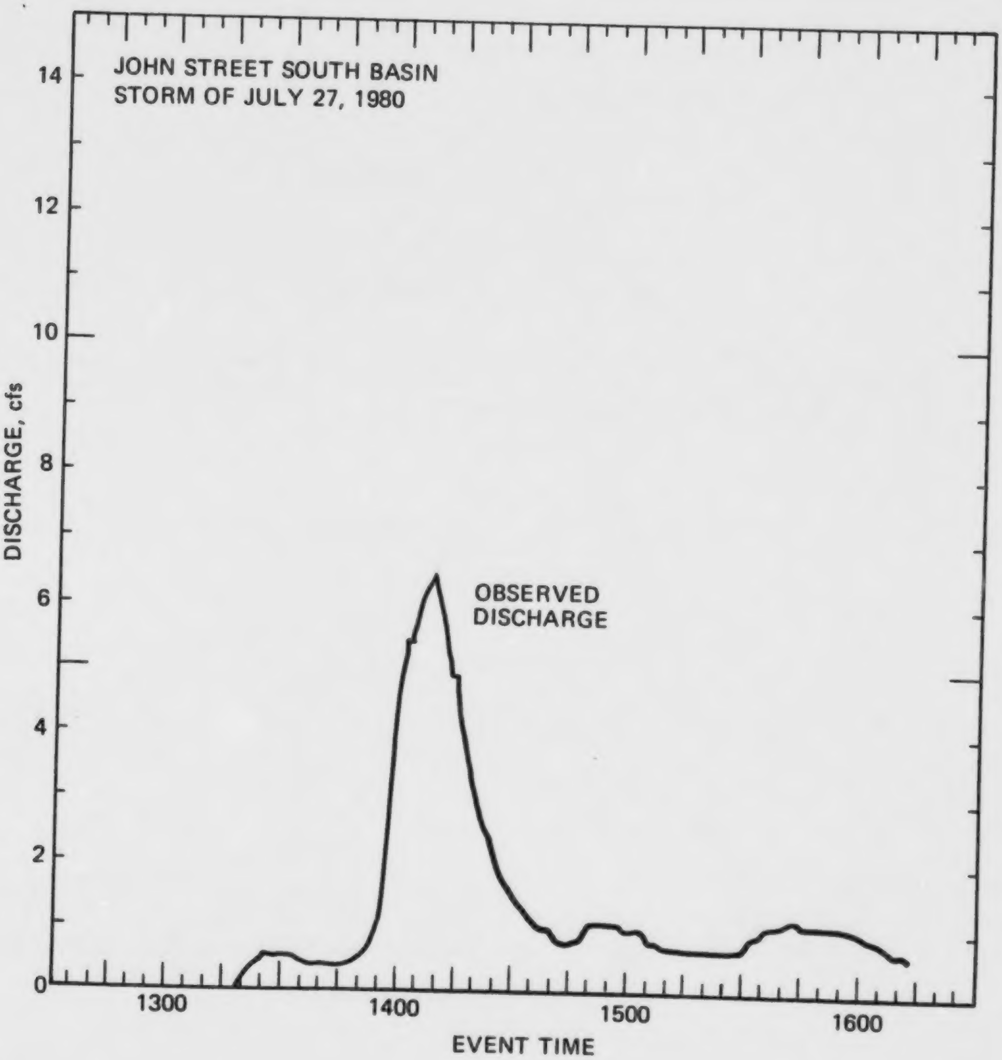

Figure 4.12 Observed runoff flow - John South - July 27, 1980

SECTION 5

QUALITY ASSURANCE/QUALITY CONTROL

EVENT DATA COLLECTION

Monitoring devices purchased for this project were tested in the ISWS laboratory before installation at the sites. The water level recorders, or bubblers, were performance tested in both one-foot and five-foot ranges. Chart readings and electronic outputs were compared with true depths of water in a test cylinder. The results were plotted and correction factors calculated to convert the electronic signal from each unit to a true depth reading. After tests on all seven bubblers it was determined that every one needed factory adjustment to reduce the erratic behavior of the signal output circuit. The recorders were sent back to the manufacturer one at a time during the first phase for this modification. The bubblers were lab tested again after modification and before installation.

The automatic samplers were also lab tested before being installed at the sites. Tests for the samplers included checks of sample distributor performance, timing of pump and purge cycles, temperature control by internal thermostat, and estimates of timer settings required to fill bottles at each site. The pump time settings were estimated after tests of pump performance in the samplers showed what each could do with various vertical and horizontal lengths of intake line.

During field installation further adjustments had to be made to equipment settings. The bubblers had to be zeroed again in the field because the lengths of air line differed at each site from the length of line used in the laboratory tests. The sampler time settings also had to be modified at every site so that sample bottles might be filled as completely as possible without overflowing.

Problems appeared quickly in the early operation of the system. The bubblers demonstrated drifting of the zero settings, especially with temperature and humidity changes, and pronounced tendencies for slowing or complete stopping of air flow. There were occasional failures of the air pumps, pressure transducers, and output circuits, as well as slippage of internal air hose connections. The samplers also exhibited failures of the stepping motors in the distributors and responses to spurious noise signals which were interpreted as instructions to sample.

The reaction to these problems was the development of a field maintenance program for the data collection system. Program tasks were carried out two to three times weekly during dry weather and immediately after storm events when the system was being reset. The goal was to identify and correct any problem of function in the system before it could interfere with proper monitoring of an event.

Under the maintenance program the bubblers, samplers, fallout collectors, rain gages, and in-pipe installations were checked at every site. The bubbler lines to the sewer flow monitoring points were blown out with compressed air to remove any material from the bubble orifice. The bubble rates were checked and set using a portable closed water column fabricated by ISWS. The electronic outputs and chart readings of the bubblers were checked against actual water depth in the sampling sites and adjustments were made if necessary. Internal connections of air lines were checked when the performance of the bubblers warranted it. If air pumps had failed or previous monitoring had indicated sudden failures of units, they were brought back from the field for repeats of the laboratory tests and, when necessary, returned to the manufacturer for repairs. The runoff samplers were checked by running test samples so that the functions of the pumps and distributors could be observed. The sampler intakes and bubbler orifices in the sewers were cleared of accumulated debris and sand every two weeks. The rainfall sensors of the wet-dry fallout collectors were cleaned weekly and the function of the cover-moving mechanism tested. The screens protecting the tipping bucket raingage mechanism from entry of debris were cleaned every two weeks and the wires leading to the remote stations checked for vandalism. The clock on the recording raingage was checked several times for accuracy and the weighing mechanism was recalibrated once in Phase I.

SAMPLE HANDLING

The sample bottles in the automatic samplers are contained in a refrigerated unit, so the runoff samples were chilled to 40°F as soon as they were collected. The field crew visited the sites to retrieve samples within two hours of the end of an event. The sampler bottles were marked with identification numbers, logged on sheets of field notes, and packed in ice for their return to ISWS offices. Notes and observations about conditions of the samples and sites were also made by the crew. As soon as the samples came in, the ones to be kept for analysis were selected and dispensed into laboratory sample bottles with their various preservatives. A proportional sample splitter was not available during most of Phase I but was later used for transferring fractions of a sample to lab bottles. The samples were again refrigerated until delivery to the IEPA laboratory in Champaign. This was normally accomplished within four to six hours of the end of the event. One of the benefits of having the IEPA laboratory analyze the samples was that only a ten-minute drive separated ISWS offices, where the samplers were preserved, and IEPA lab. Strict accounts were kept of the samples used and analyses requested for each event. When results of analysis were returned, the values were checked for consistency against others from that site and the other sites for that event and previous events. The field notes concerning the event were also examined for clues to reasons for unusual values. Any unlikely values with no apparent explanation for its occurrence was discussed with the laboratory personnel to determine whether there was any likelihood of error in analyses or reporting. Limited volumes of samples made reruns of questionable analyses impossible.

LABORATORY PROCEDURES

The IEPA laboratory in Champaign practices a quality control program in its handling and analysis of samples which was documented in March of 1979 for in-house use. The document was too lengthy for reproduction here but is available from the laboratory.

SPECIAL METALS

In January 1981 USEPA supplied materials and instruction to each NURP project location, requesting that a set of special runoff samples be collected and shipped to their laboratory for total, total recoverable, and dissolved metals analyses. In compliance with this request, ISWS collected and processed eight samples. Five of these were splits from composite samples taken at each site during the event of June 9, 1981. The remaining three samples were grab samples from one site collected at different times during the event of June 12, 1981. Portions of seven of the eight samples were kept for analysis of total and dissolved metals by the IEPA laboratory. Altogether, concentrations of eleven metals were determined by both laboratories from the same samples. In January 1982 a summary of results from individual samples and averages for the eight samples was sent by USEPA. A similar summary was prepared on the results from the seven samples IEPA analyzed. Table 5.1 is a comparison of the concentrations of four metals determined by IEPA and USEPA laboratories for these samples. There is generally good agreement between the results. Differences in sample preservation, sample handling, and analytical techniques could certainly account for the variation in the results.

SAMPLER PERFORMANCE

On three occasions, simultaneous automatic and manual samples of storm runoff were collect at a site during an event. The purpose of this sampling was to determine how well a sample collected by automatic means represented the quality of the flow at that moment. It was considered possible that automatic sampling through the fixed intake located near the invert of the storm sewer might produce a sample not representative of the flow because of incomplete mixing in the pipe. In each test several pairs of samples were taken. Each pair consisted of one 1000-ml sample pumped by the automatic sampler and another 1000-ml sample collected manually in the sewer. The manual sample was collected in a manner to represent the entire cross-section of flow and was considered the standard against which the automatic sample should be compared. Both samples in each pair were sent to the IEPA laboratory for analysis of total suspended solids and total dissolved solids.

Results of these samples are shown in table 5.2. The first set was collected in November 1979 at site 2. In the three pairs the solids

Table 5.1 Special Metals Comparison -- Concentration of Four Metals in Samples Analyzed by IEPA and USEPA Labs

	Lead				Copper				Iron				Manganese			
Composite Samples	T		D		T		D		T		D		T		D	
9 June 1981	I	U	I	U	I	U	I	U	I	U	I	U	I	U	I	U
Site 1	.71	.580	<.01	.040	.06	.050	.008	.020	7.4	10.8	.35	.040	.89	.860	.11	.120
Site 3	.21	.200	<.01	<.040	.04	.040	.020	.020	1.9	3.74	.063	.040	.11	.140	.007	<.010
Site 4	.24	.180	<.01	<.040	.03	.020	.010	<.020	2.8	3.62	.093	.090	.36	.320	.008	.010
Site 5	.36	.260	.01	<.040	.11	.100	.011	<.020	11.0	18.0	.21	.170	.71	.650	.16	.160
Discrete Samples Site 2																
12 June 1981																
Sample 1	.41	.340	--	<.040	.05	.020	--	<.020	4.6	6.74	--	.120	.30	.280	--	.130
2	.68	.690	--	<.040	.04	.060	--	.020	7.5	12.40	--	.080	.65	.740	—	.050
3	.27	.140	--	<.040	.02	<.020	--	<.020	3.6	3.65	--	.070	.36	.240	—	.030

All values in mg/l
T = total
D = dissolved
I = IEPA determination
U = USEPA determination

concentration ranged from 7 to 17 percent higher in the automatic sample. The second set, from site 4 in May 1981, showed little effect of sample type on the solids load. However, these samples were collected well after the peak flow of the event, while the flow was gradually receding and after the greatest part of the solids load for the storm had already been moved. The third set, from site 2 in June 1981, showed very high suspended solids concentrations in both types of samples, but again those in the automatic samples were substantially higher until well after the peak flow.

These findings suggest that the use of the automatic sampler with the intake fixed near the invert of the sewer may have resulted in calculation of larger event loads than would be determined by more representative sampling. This could be true not only for suspended solids but for any constituent which exists principally in the suspended phase in runoff. This would influence event, seasonal, and annual loads and materials balances.

Table 5.2. Automatic Versus Grab Sampling

Sample set	Date (mo/yr)	Site	Total suspended solids conc. (mg/l) Manual	Total suspended solids conc. (mg/l) Auto	Total dissolved solids conc. (mg/l) Manual	Total dissolved solids conc. (mg/l) Auto	Estimated flow (cfs)
1	11/79	2	84	98	-	-	-
			83	97	-	-	-
			90	97	-	-	-
2	5/81	4	22	20	115	109	0.8
			25	26	99	102	1.2
			22	24	92	96	0.9
			20	22	98	95	0.6
3	6/81	2	408	540	190	212	0.5
			563	663	144	154	4.8
			426	489	130	127	1.3
			152	160	109	113	0.9

BUBBLER PERFORMANCE

A major concern in data collection was whether the water level recorder, or bubbler, was producing a true reading of depth of flow at a sampling site. To determine this, a test was devised in which the depth of water above the bubbler orifice in the sewer was physically measured during an event. Simultaneous readings of the bubbler output signal to the telemetry system were made and converted into depth values and the results of the two sets of measurements compared. The precision of the two measuring methods was roughly equal, about ±0.02 ft. This test was performed at site 2 on June 12, 1981, and the results are shown below:

Time	Manual depth measurement (ft)	Bubbler depth measurement (ft)
0915	0.20	0.14
0916	0.20	0.17
0919	0.70	0.67
0926	0.60	0.59
0930	0.45	0.47
0933	0.40	0.43
0938	0.30	0.30
0940	0.30	0.29

The results of this test show that the bubbler, when properly calibrated and adjusted for site conditions, produced a reliable measure of depth of flow in the sewer.

Another problem with respect to the bubblers was erratic behavior. It was noted early in the project that each unit showed slight, individual deviations from a perfect 1:1 representation of depth of water above the orifice. It was also observed that with passage of time and changes in temperature a unit's zero setting would drift off its proper point and its bubble production would gradually slow down and stop. The latter problems were handled with the institution of frequent checks of zero setting and bubble rate for each unit in the field. To determine the accuracy of depth measurement by each bubbler, a laboratory procedure was devised. In a test a bubbler air line was attached to a water column in which the level could be varied throughout the nominal range of the bubbler, and simultaneous readings of actual water depth and metered depth reported by the bubbler were made. For each test a figure similar to figure 5.1 was drawn, plotting metered depths against actual depths. From the results and the plot a correction factor was calculated for the bubbler. All values reported subsequently by that bubbler in routine data collection were multiplied by its correction factor so that accurate depths would be used in flow calculation. Tests were repeated occasionally during the sampling season on every active unit whether or not it had shown signs of erratic performance. Tests were mandatory after a damaged bubbler had been repaired and before it was placed in use again. Long-duration tests in the laboratory showed that the multiplier required for correct depth representation did not change significantly with time.

SYSTEM MAINTENANCE

Early in the operation of the data collection network, it became apparent that a routine of visits to the remote sites for checking and adjusting equipment would have to be established to assure proper performance of the system during storms. The following is a schedule of tasks carried out during the periodic site visits:

Frequency	Task
2-3/week	Bubbler - Check bubble rate, adjust zero setting, blow out air line
	Sampler - Check for spurious samples

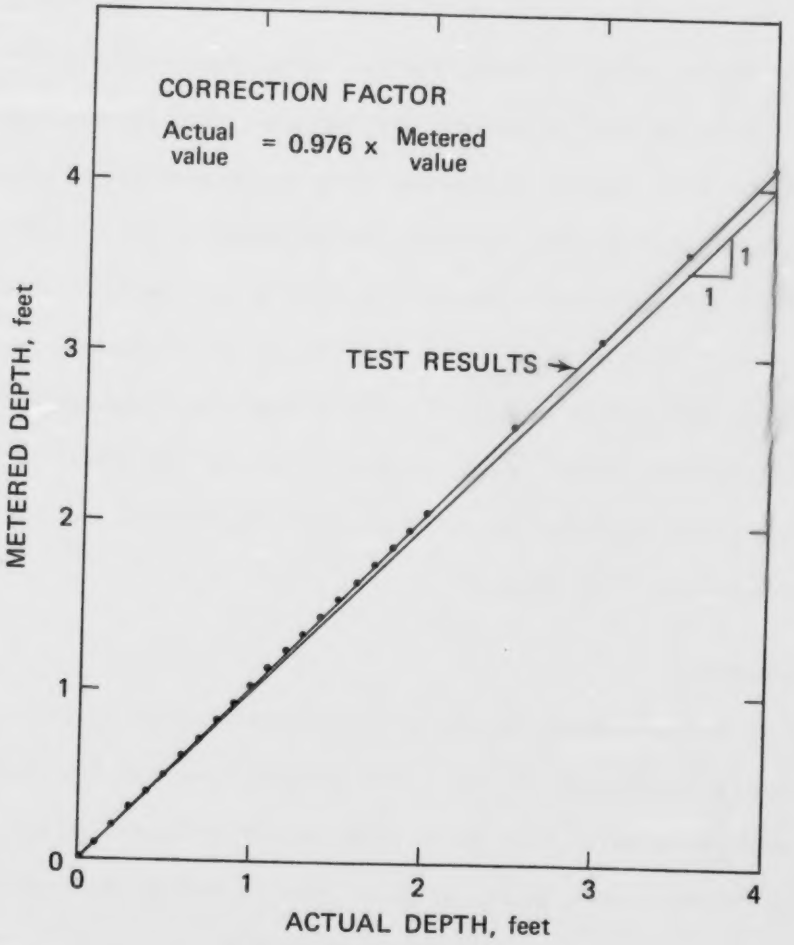

Figure 5.1 Example - bubbler performance curve

1/week Bubbler - Compare electronic output to physical measurement of depth in pipe and adjust bubbler accordingly

Sampler - Check sampler function by running through purge/pump/purge cycle, then reset

Raingage (recording) - Change chart, wind clock, refill ink supply

Wet/Dry Samplers - Check basic functions: power supply, precipitation sensors, cover movement mechanism

Micro-Basin - Clean out trash, litter, leaves, etc., accumulated in catch basin

1/month Bubbler - Clear orifice installation in pipe of sediment and debris

Sampler - Clear intake installation in pipe of sediment and debris

Raingages (tipping bucket) - Clean screens and buckets of vegetation, fine particles, and other interferences to performance.

In addition to these routine checks of the sites, the field crew investigated any problem discovered at a site or any suggestion of a problem indicated by peculiar responses from the remote stations to the interrogation from the central station.

STREET DIRT SAMPLING PROCEDURE EVALUATION

In March 1981 the ISWS crew traveled with its street dirt sampling equipment to Milwaukee, Wisconsin, the site of a NURP project run by the Wisconsin Department of Natural Resources. The purpose of the journey was to compare the ISWS street dirt sampling procedure to the procedure being used in the Milwaukee study. Two kinds of tests were performed. In the first, the two sets of equipment were operated in the Milwaukee study areas, collecting samples consisting of identical numbers of subsamples and passes across the streets. The total weights and particle size distributions of the material collected by the two methods were compared for corresponding samples. In the second test, pairs of adjacent plots on an asphalt street and a concrete street were cleaned first with one system, then with the other, and last with a wet vacuuming technique. One of each pair of plots was cleaned first with the Milwaukee system, then with the ISWS system; the reverse of this order was used on the other. The loads in each sample from each plot were examined to determine what the total load on the plot had been, how much had been collected by the first cleaning system used, how much had been left behind by the first and collected by the second, and how much had been left behind by the second and collected by the wet vacuum.

The results of the first tests appeared to favor the Milwaukee procedure. In six out of seven instances the load picked up by the Milwaukee system was greater than that collected by the ISWS system. The ISWS sample loads ranged from 57-93% of the Milwaukee loads in those six cases; in the seventh the ISWS sample was 10% larger than the Milwaukee sample. Particle size analysis of the samples indicated that proportionally more of the finer size particles were being collected by the Milwaukee procedure as well. However, both crews recognized that apparently minor differences in the type of intake mounted on the vacuum wand and in the effort used in applying the vacuum to the street surface, especially at the curb, could be at least partially responsible for the differences between corresponding sample loads.

The second set of tests demonstrated that the capability of the two systems was about the same. For each test plot, the weights of the material taken off by the sequential dry vacuuming were added and called the dry load. The solids collected in the following wet vacuuming were measured and that weight added to the dry load for the total load on the test plot. On the concrete street, the Milwaukee system collected 95% of the dry load, 82% of the total load; the ISWS system collected 97% of the dry load, 88% of the total load. On the asphalt street, the Milwaukee system captured 86% of the dry load, 54% of the total; the ISWS system captured 88% of the dry load, 57% of the total. On the concrete street the material picked up by the wet vacuum after two dry vacuumings represented 10-14% of the total loads; on asphalt, 35-37% of the totals. With respect to the material less than 63 microns in size, only 35-40% of it on the concrete street and 18-24% on the asphalt street were removed by the first dry vacuuming. After both passes by dry vacuum, 55-59% of the material smaller than 63 microns on concrete and 72-73% on asphalt still remained for the wet vacuum to collect. Relatively, though, the Milwaukee equipment performed better collection of fine particles on concrete, while the ISWS equipment had better collection of fines on asphalt.

Consideration of the results of the second set of tasks and interpretation of the results of the first set, with regard to possible influences of slight operational differences, led to the conclusion that the ISWS method of collecting street dirt samples adequately represented the loads at the sampling points. This reinforced the decision to continue into the 1981 sampling season with only minor modifications to the sampling procedure.

FLOW MEASUREMENT

Tests were conducted in 1981 to determine the accuracy of theoretical flow rating curves developed for the monitoring sites. Two basic types of tests were used. The first was the actual physical measurement of the volumes of flow passing over the free overfalls at the Mattis sites. This was done twice during low flow at each of the two sites with the corresponding depth of flow being recorded each time. While the depth and flow volume measurements were imprecise, especially at Mattis North where a small misalignment of the sewer had a great impact on such measurements of low flow, they still represented real points on the low ends of the rating curves. The results of this effort are given below:

Site	Depth (ft)	Measured flows (cfs)	Theoretical flow (cfs)
Mattis North	0.12	0.004	0.116
	0.12	0.012	0.116
Mattis South	0.07	0.027	0.035
	0.09	0.040	0.060

The second type of flow rating test was dye dilution. At least two of these tests were run on each of the sites. In the test, a solution of Rhodamine-WT dye of known concentration, about 3%, was injected into the storm flow at the first manhole upstream from the site being tested. The dye was pumped at a rate of 48 ml per minute into a tube attached to the rim of the manhole which conveyed the solution directly to the flow outlet. An angled plate had been bolted to the bottom of the sewer to improve mixing, and the dye was dropped into the turbulent region of flow immediately downstream from the plate. A test was performed at only one site during a storm. As soon as the pumping of the dye solution began, the automatic sampler at the site was started manually with samples taken at two-minute intervals. The start of the sampling was timed so that each sample would be taken at the same moment that the telemetry network was inquiring for and recording the flow depth from the site. This record of depths at sampling times was supplemented by occasional on-site observations. The duration of each test was 20-40 minutes, at the end of which the pumping of dye solution was stopped and several more samples were taken to document the washout of the dye from the sewer.

To analyze the results of the test, the concentration of dye in each sample was determined with a fluorometer. Since the concentration and rate of the injection solution was known, the flow rate corresponding to the sample was calculated by dividing the sample dye concentration into the product of the concentration and flow rate of the injected dye. After this was done, the flow depths obtained by the telemetry system at the time of each sample were used to calculate the flow rate according to the theoretical rating curve and the results of the two methods were compared.

Table 5.3 contains a summary of results from a dye injection test conducted on Mattis North basin during the event of August 5, 1981. The event began at 1238 and lasted almost six hours, with a total rainfall accumulation of about 1.7 inches. The dye test was run in the first hour of the event, during which time 0.67 inch of rainfall on the Mattis North basin. Starting at 1248, a dye solution with a concentration of 3.25×10^7 ppb was pumped at a rate of 48 ml per minute into the storm flow in the manhole immediately upstream of the monitoring site. Automatic sampling of the runoff flow at two-minute intervals was started at 1249 and continued until 1317, producing a total of 15 samples. These were analyzed for dye concentration and the runoff flow rates corresponding to the times when the samples were collected were calculated in the manner described above. From the telemetered event data for the site, the flow depths at the sampling times were extracted and the theoretical flow rates corresponding to the depths were determined from the rating curve. Comparison of the flows calculated from the rating curve and the dye test results shows that the values from the rating curve are lower in every instance. This

Table 5.3. Results of Dye Test - Mattis North - August 5, 1981

Time	Tele-metered depth (ft)	Rating curve flow Q_T (cfs)	Dye conc. in sample (ppb)	Calcu-lated flow Q_c (cfs)	Ratio Q_T/Q_c
1249	.60	3.34	173	5.32	.63
51	.67	4.16	155	5.94	.70
53	.74	5.05	145	6.35	.80
55	.67	4.16	153	6.02	.69
57	.60	3.34	184	5.00	.67
59	.53	2.61	208	4.43	.59
1301	.58	3.12	224	4.11	.76
03	.60	3.34	214	4.30	.78
05	.74	5.05	141	6.53	.77
07	.79	5.73	112	8.22	.70
09	.86	6.73	96	9.59	.70
11	.86	6.73	90	10.23	.66
13	.82	6.15	104	8.85	.69
15	.72	4.78	114	8.07	.59
17	.62	3.57	165	5.58	.64

was not true in the results of all tests, however. In three tests at Mattis North, two suggested that the rating curve overestimated the flow and one (August 5) that it underestimated flow. The results of tests on the other sites were similarly inconclusive. Though it was not the case with the Mattis North test on August 5, a problem with most of the tests was that only a narrow range of flows were tested during the 40-minute maximum duration, and that these were often at the low end of the flow rating curves for the sites. It may be that in spite of efforts to improve the mixing, the injected dye was not completely dispersed throughout the flow by the time it reached the sampling point. The sampling intake being fixed to the invert of the sewer and thus not truly representing the entire cross section of flow might have contributed further to improper sampling of the dyed runoff. In any event, the results of these tests were not considered sufficiently definite to justify changes to the rating curves based on them.

SECTION 6

ANALYSIS OF DATA

STREET DIRT

Street Dirt Loads

Figures 6.1 and 6.2 display the results of street dirt sampling on each basin during the 1980 and 1981 sampling seasons. The figures contain three lines each. The points connected by the upper line represent the total street load calculated from sample results and expressed in grams per curb meter (g/curb-m) for each sampling day. The middle line identifies the portion of the total street load which is less than 250 microns in size. The lower line connects points representing the median particle size of the total street load. The calculations of the partial street loads and the median particle sizes are based on the measured total street load and the determination of particle size distribution in the street dirt samples from each sampling day. The lines between the plotted points are drawn as indicators of the direction of load changes between sampling dates and are not intended to portray the definite loading condition on any non-sampled day.

Several aspects of these curves are noteworthy. In 1980, there was a pronounced effect of municipal sweeping on the street load in John North and a lesser effect on the load in Mattis South when the twice-weekly sweeping of the two basins began in July. For John North, a comparison of averages of street loads for the periods before and after the start of sweeping showed a change from 50 to 19 g/curb-m, a reduction of 62%. A similar comparison for Mattis South showed a change from 115 to 88 g/curb-m, a reduction of 23%. The control basins continued to show high

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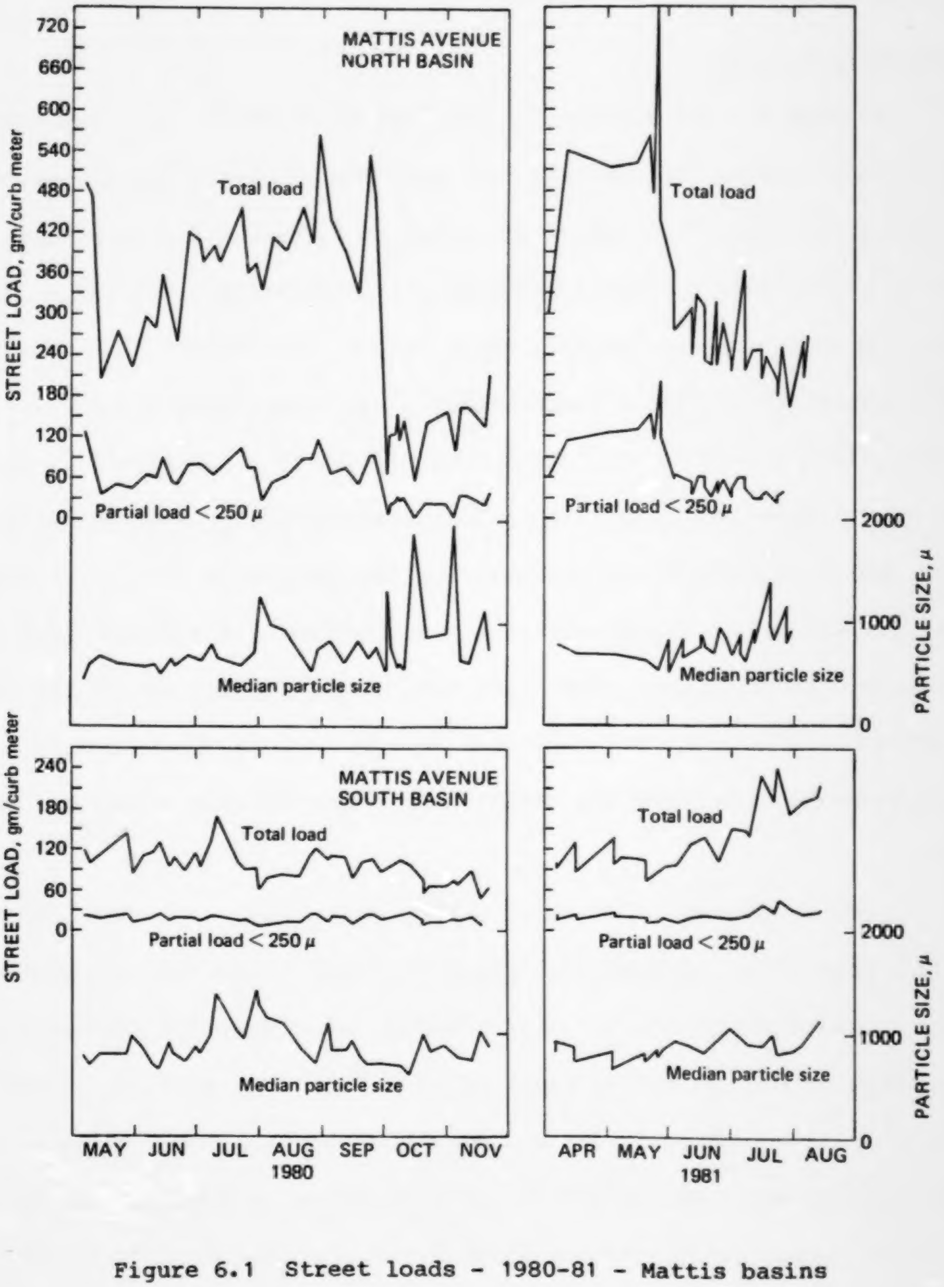

Figure 6.1 Street loads - 1980-81 - Mattis basins

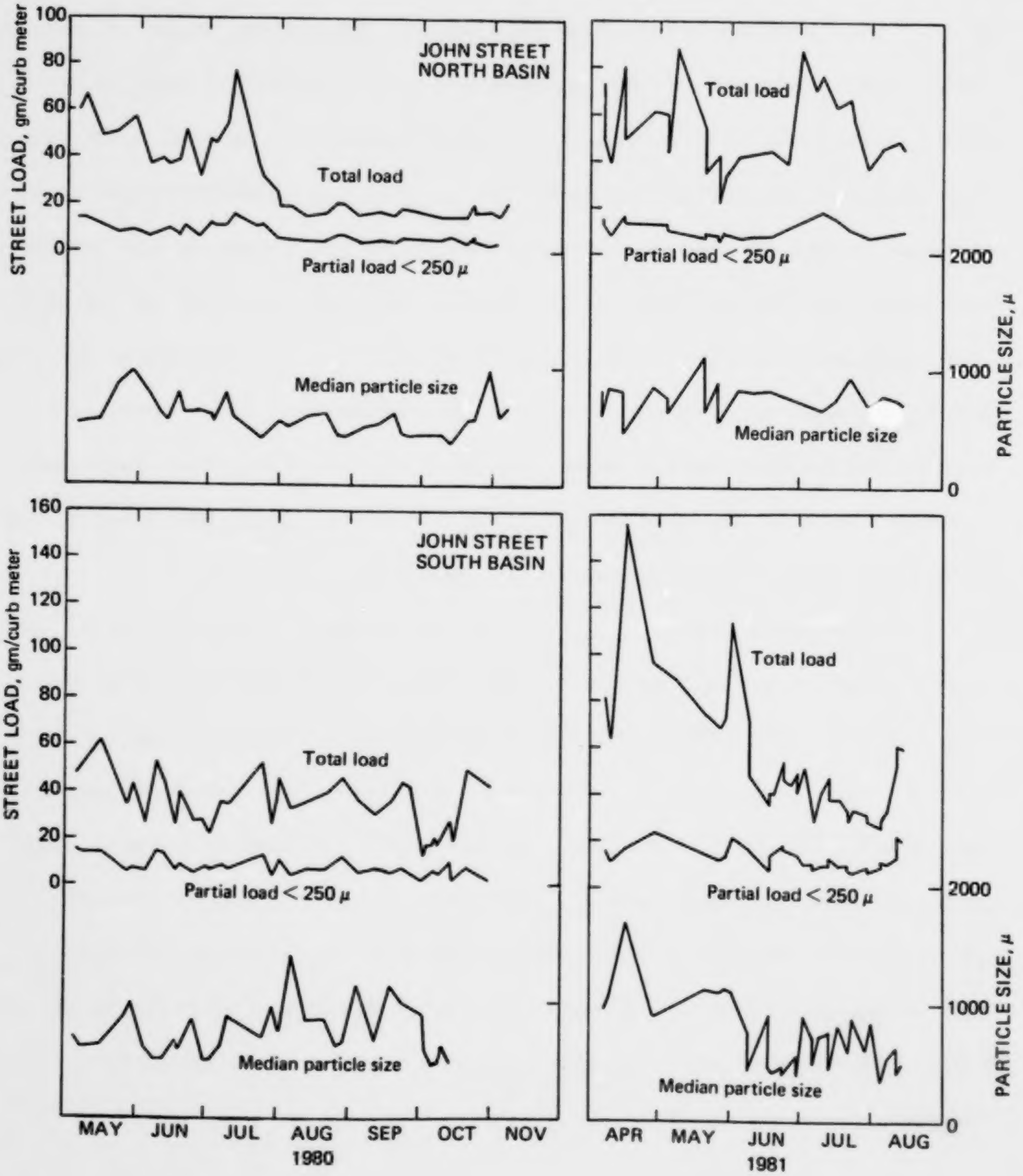

Figure 6.2 Street loads - 1980-81 - John basins

load and variability throughout the sweeping period until the cleanup at the end of September. The average street loads during the period prior to the cleanup were 381 g/curb-m on Mattis North and 39 g/curb-m on John South. The reduction of load in both control basins due to the cleanup was quite large, from 465 to 100 g/curb-m for Mattis North and from 42 to 13 g/curb-m for John South. The fairly quick return of the John South basin to a load condition like that prior to the cleanup is attributable to the seasonal effect of leaf and litter load during the autumn in the residential area. The Mattis North basin did not show such a return to the high load conditions of summer because it does not have the vegetative cover to supply the load of leaf and litter as the residential basin does, and because the higher traffic speeds and volumes help clear that load from the streets. Much of the load removed from the Mattis North basin had likely lain there since deposition after the spring cleanup.

In 1981 Mattis South and John North were swept once per week in April and May, during which time the average street loads were 94 and 47 g/curb-m respectively. The other basins were left unswept through those two months. Their average loads were 560 g/curb-m for Mattis North and 90 g/curb-m for John South. From June to August, Mattis North and John South were swept once per week, and their average loads dropped to 247 and 40 g/curb-m respectively. Meanwhile the other basins were left unswept and their average loads rose to 169 g/curb-m in Mattis South and 55 g/curb-m in John North. Table 6.1 summarizes the average loads and sweeping activity for the basins for both years.

Table 6.1 Average Street Loads on Study Basins During 1980-81

	Mattis North	Mattis South	John South	John North
May - July 1980				
Sweeping Frequency	None	None	None	None
Load (g/curb-m)	381	115	39	50
July - November 1980				
Sweeping Frequency	None	2/wk	None	2/wk
Load (g/curb-m)	381	88	39	19
March - May 1981				
Sweeping Frequency	None	1/wk	None	1/wk
Load (g/curb-m)	560	94	90	47
June - August 1981				
Sweeping Frequency	1/wk	None	1/wk	None
Load (g/curb-m)	247	169	40	55

A difference between the street dirt sampling programs for 1980 and 1981 was that, in the second year, sampling was performed on the experimental basins both before and after street sweeping, instead of only after sweeping as had been done in the first year. This was done to provide better information on sweeper performance. The results of this change are visible in the street load plots for the basins for 1981, where two values are plotted for the experimental basins for every day of sweeping. In all but a few cases, the load after sweeping represented a significant reduction from the load before sweeping. However, on a few days when the initial loads were low, the load after sweeping exceeded that measured before sweeping. This will be discussed later in the report.

Inspection of the partial street load lines shows that municipal sweeping was less effective on material smaller than 250 microns than on the total basin load. This is expected since the mechanical sweeper is designed to remove large, objectionable material including trash, litter, and leaves. The median particle sizes seemed to hold fairly steadily around 750 through the non-sweeping part of 1980 on all four basins. When twice-weekly sweeping began on John North, the average median particle size of the street load there dropped to about 550μ. No comparable change was observed in the material from the other swept basin, Mattis South. In the two control basins a cleanup at the end of September produced opposite effects in the median particle size: in John South it dropped to 550 and became less erratic from day to day, while in Mattis North it showed extreme fluctuations through the next two months. In 1981 each basin was swept at a frequency of once per week for some period. Both John North and John South demonstrated the expected reduction in median particle size of load during sweeping, compared to non-sweeping periods. In Mattis South the same behavior was seen, but in Mattis North the trend of this parameter was an increase even during the regular sweeping. For all four basins the results of sampling street load before and after sweeping usually show the median particle size of the remaining load to be less than that of the initial load. There were a few cases, however, generally on days of low initial load, when the reverse was seen.

Deposition and Accumulation

Figure 6.3 represents the deposition and accumulation of street dirt in the four basins during the 1980 and 1981 seasons. For every day of sampling in a basin the total street load was calculated and expressed in g/curb-m. A value for days since the basin was last cleaned, either by sweeping or by a rainfall of at least 0.03 inch, in no more than 150

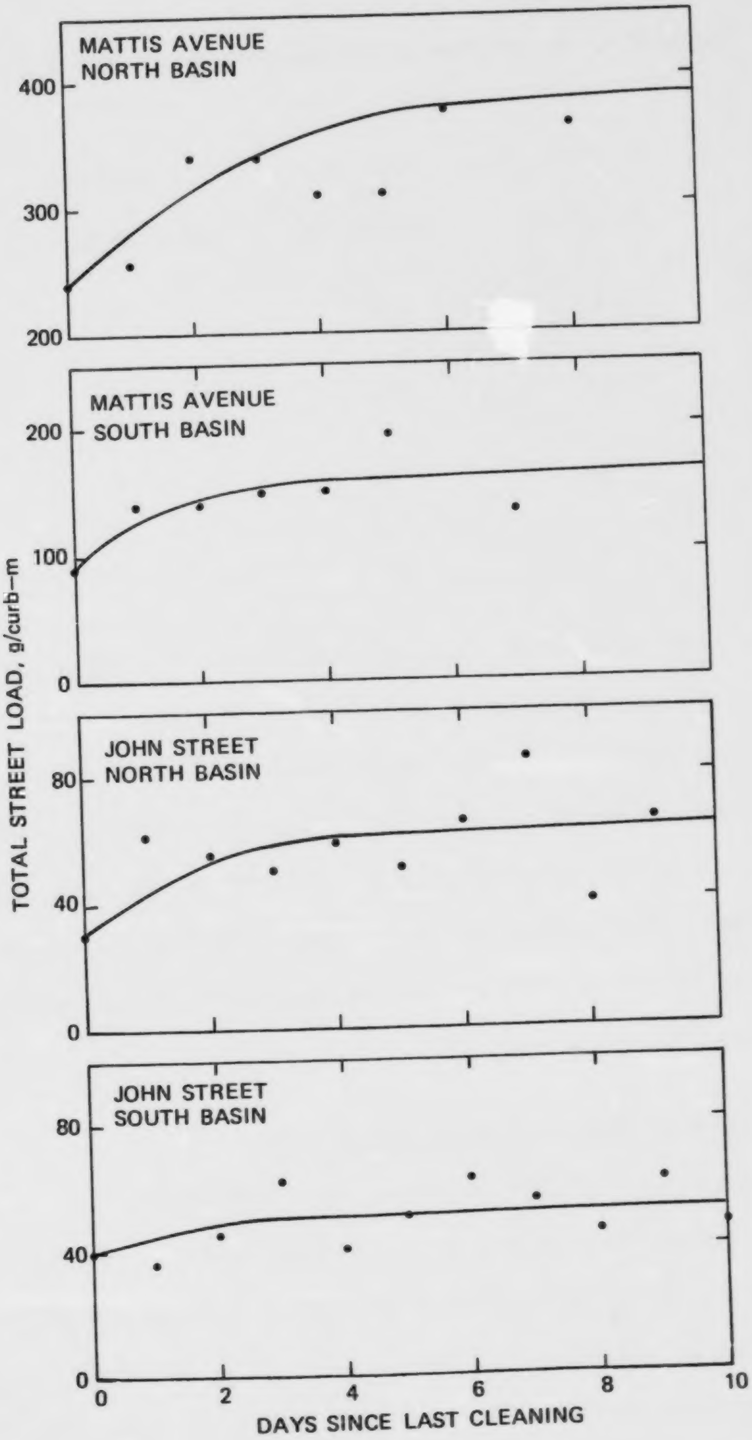

Figure 6.3 Deposition and accumulation of street loads

Table 6.2. Deposition and Accumulation of Street Dirt by Basin

Basin	Initial Load (g/curb-m)	Maximum Load (g/curb-m)	Deposition Rate (g/curb-m/day)	Days to Maximum Load
MATTIS NORTH	240	400	35	20
MATTIS SOUTH	90	175	30	18
JOHN NORTH	30	64	14	14
JOHN SOUTH	40	52	6	12

minutes, was associated with each street load determination. All street load values corresponding to each number of elapsed days were averaged and the points plotted. In some cases there was only a single load value for a particular number of elapsed days. These points were plotted with the others but were considered less significant in the curve fitting procedure. The curves drawn through the points were modified logarithmic curves. Estimates of several key parameters of street loading were taken from the curves and listed in table 6.2.

Characteristic Particle Size Distribution

Figure 6.4 contains bar diagrams of average particle size distribution of street surface solids on the four basins. The size ranges in the figures were based on the sieve set used in sample analysis from July 1980 to the end of the project. The particle size data from May and June 1980, which had been collected using a different sieve set, were transformed for inclusion in this summary. The values plotted in the figures are the maximum, minimum, and mean of percentages determined in each particle size

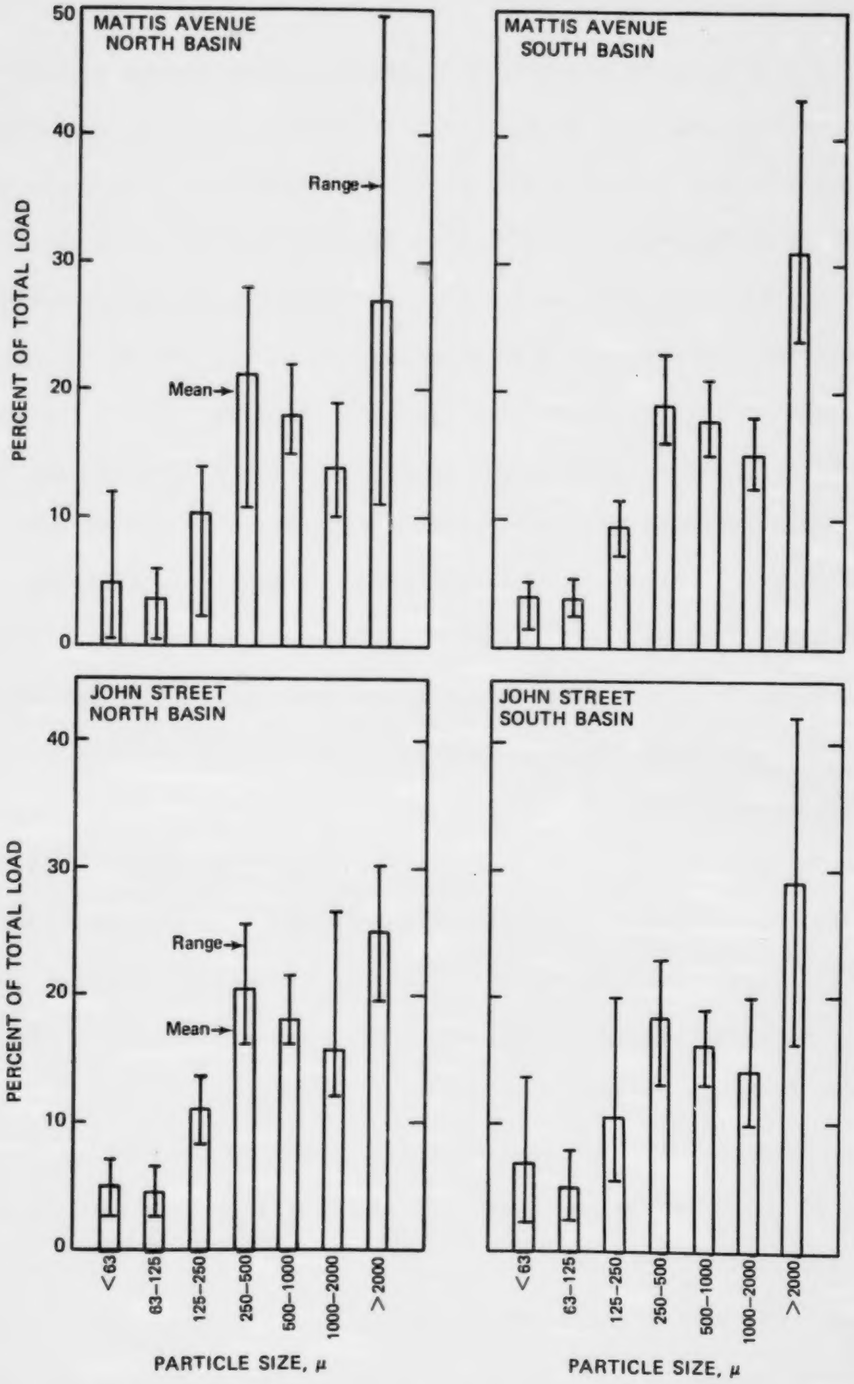

Figure 6.4 Characteristic particle size distributions of street loads

range from material collected each sampling day during periods of no sweeping on the basins.

The similarity of these results, not only between paired basins but also between the John basins and the Mattis basins, is surprising. Earlier analysis in the Second Annual Report had suggested that there might be distinct differences in loads from the residential and commercial areas as well as the individual Mattis basins. However, these plots suggest small differences in particle size distribution in all but the largest material. The coarse material showed the greatest variation between basins. Fine material appeared to be only a small part of the total in any basin. The sampling procedure may have had an influence in yields of both coarse and fine material, since irregularity of occurrence on the street was greater with larger solids, while fines might never be collected or might be lost at several steps in the sample handling process. Other influences include street type, condition, and texture, traffic type and speed, land use, and climate. The latter is especially important since storms with moderate rainfall are frequent here. Fines are moved regularly due to such small storms, while coarse materials tend to accumulate through several small events and to move only when a major storm occurs. Whatever the effects of these many influences, it appears that the particle size distribution for street load was very similar for all four basins.

During a period of no sweeping on a basin, the particle size distribution of solids would be expected to shift gradually toward an increase in the amount of coarse material present, due largely to the reasons given above. The median particle size would increase also. On the other hand, during a period of regular street sweeping the size distribution would shift toward a greater fraction of fines than would be present without sweeping, due to systematic removal of the larger material by the sweeper. In this case the median particle size would decrease. The data shown in table 6.3 are from May-September 1980. The table shows the fractions of material less than 250μ and less than 1000μ and the median particle size in the street load from all four basins, grouped and averaged for periods of three to five weeks. Street sweeping at a twice weekly frequency began in Mattis South and John North after the third group of data. The set terminates with the cleanup of the control basins at the end of September. In both Mattis North and John South, the control basins, there was a general trend of a decreasing fraction of the total associated with the finer particles and an increase in the median particle size throughout the season. In John North the effect of sweeping was clearly evident, with a sharp increase in the fraction of the total load represented by the smaller sizes and a decrease in median particle size. This effect was less evident in Mattis South. This was due in part to the fact that Mattis South is mostly a four-lane street and only parts of the outer lanes are swept, while solids are distributed from curb to curb through a median strip. Differences in its geometry and slope from the other basins increase its potential for washoff and might have influenced this representation of effect.

Table 6.3. Partial Loads and Median Particle Sizes of Total Street Loads During May-September 1980

BASIN

Group	Date	Mattis North <250μ	Mattis North <1000μ	Median particle size (μ)	John South <250μ	John South <1000μ	Median particle size (μ)
1	May 5-27	21	66	590	23	61	720
2	May 29-Jun 26	21	64	600	22	61	670
3	Jun 30-Jul 15	20	61	690	25	62	630
4	Jul 21-Aug 26	18	57	800	20	55	860
5	Aug 28-Sep 26	18	59	730	19	53	930
		Mattis South			**John North**		
1	May 5-27	18	57	770	21	62	620
2	May 29-Jun 26	17	56	800	20	59	710
3	Jun 30-Jul 15	15	51	1010	22	62	630
4	Jul 21-Aug 26	15	49	1060	28	67	510
5	Aug 28-Sep 26	19	55	820	29	69	480

STREET DIRT QUALITY BY PARTICLE SIZE

A complete understanding of the effect of street sweeping on runoff quality requires knowledge of not only the load available for washoff and its particle size distribution but also the amount of any constituent of interest which is present in each particle size group. In the five size groups below 1000μ, composites of several days' samples from a basin were analyzed for 18 constituents. The results were expressed as milligrams (mg) of constituent per kilogram (kg) of dry street solids. Figure 6.5 consists of bar diagrams representing the lead concentration by particle size group for the four basins. The plotted values represent concentrations in the total street load averaged for all periods of monitoring load on a basin while no street sweeping was occurring. In the case of lead, Mattis South had the greatest concentration of all basins in every size group and John South had the least. The high concentrations in the Mattis

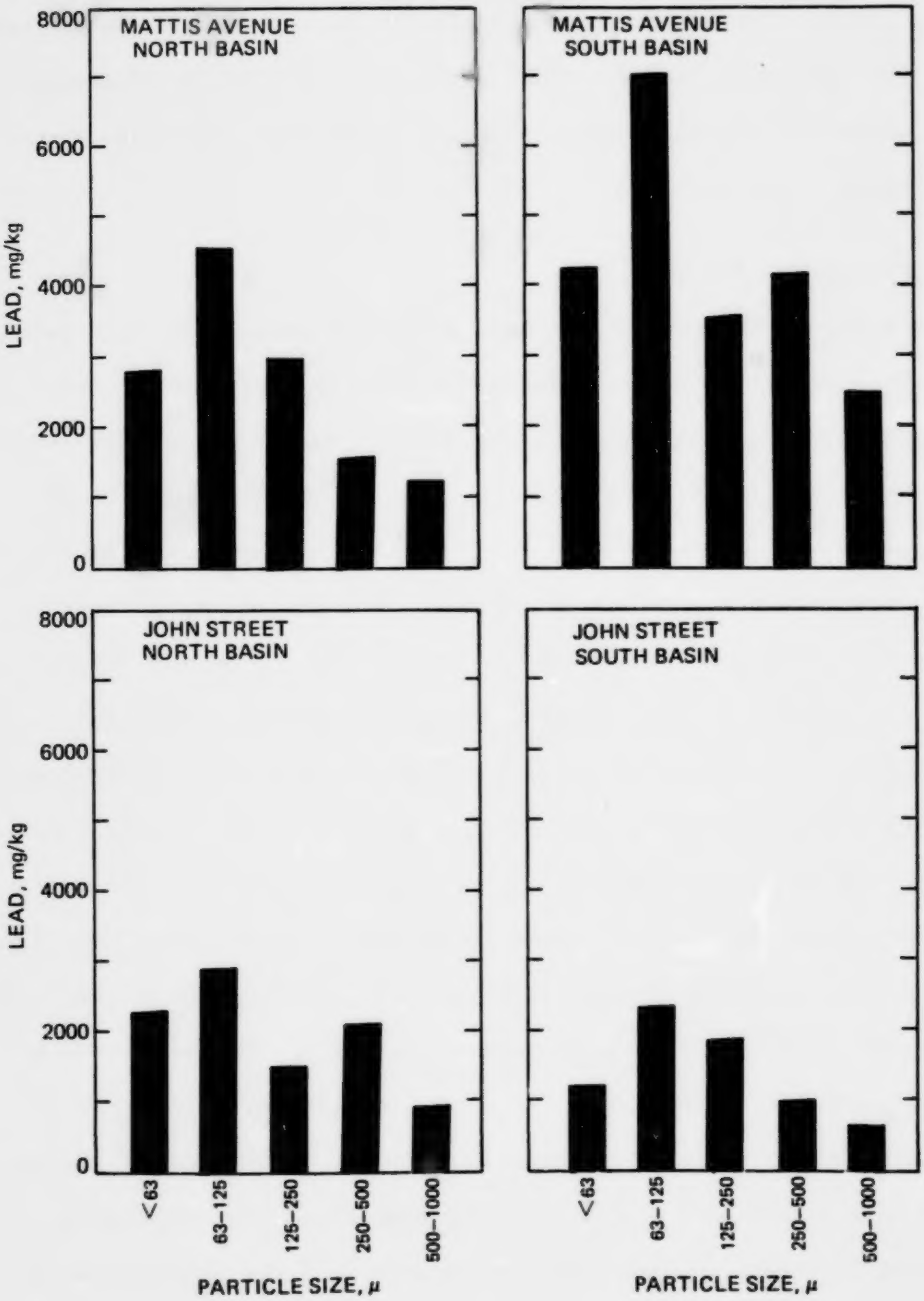

Figure 6.5 Average concentration of lead by particle size group in street load

Avenue basin loads, compared with those in the John Street basin loads, are due to the much greater traffic in the commercial basins. Table 6.4 contains average concentrations of six other constitutents along with lead by particle size group for each basin. The six additional constituents include ammonia-nitrogen, Kjeldahl nitrogen, phosphorus, chemical oxygen demand, copper, and iron.

Constituent Load On Basin

For a calculation of the load of a particular constituent on a basin, the street load in each particle size group must be multiplied by the concentration of the constituent in that size group and the products added for a total. From the data presented so far, a reasonable estimate of constituent load on a basin can be made easily. Combination of the characteristic particle size information and the constituent concentrations by particle size group and basin produced the data for figures 6.6 through 6.11. Each of these figures contains four plots, one per basin, and represents the incidence of a single constituent. The values plotted were derived by multiplying the mean percentage of total street load in a particle size group on a basin, figure 6.4, by the concentration of the constituent corresponding to the size group in the basin, table 6.4. The resulting value is an estimate of the load in mg of the constituent in that size group for every kg of total street load on the basin. The sum of the five values in each plot is the load in mg of the constituent in material smaller than 1000μ for every kg of street load. Because the two largest particle size groups were not analyzed for constituent concentrations, this remains the best estimate possible from the data. While according to the plots in figure 6.4, the five smaller particle size groups account for only

Table 6.4. Average Concentrations of Seven Constituents in Street Dirt by Particle Size Group for Each Basin (data for no sweeping periods only)

	Ammonia-Nitrogen (NH_3)	Kjeldahl Nitrogen (K-N)	Phosphorus (P)	Chemical Oxygen Demand (COD)	Lead (Pb)	Copper (Cu)	Iron (Fe)
MN							
500-1000	10	383	135	37700	1142	66	36100
250-500	14	350	135	31300	1642	99	25700
125-250	25	679	261	61800	3049	91	31800
63-125	37	792	474	97300	4612	118	42700
<63	21	892	421	114300	2810	126	28400
MS							
500-1000	4	463	219	86120	2471	31	59760
250-500	6	203	101	48260	4144	34	39630
125-250	7	493	150	78590	3511	43	36710
63-125	15	2990	529	169100	7032	109	48720
<63	8	1270	388	111800	4264	132	29190
JS							
500-1000	30	5720	853	270500	614	44	24060
250-500	29	5760	629	131100	959	47	20900
125-250	81	5370	606	169700	1826	92	26070
63-125	113	7550	926	251800	2278	128	31670
<63	92	4240	667	172200	1247	113	22520
JN							
500-1000	8	1700	273	307800	918	21	33260
250-500	6	540	148	116600	2128	30	22620
125-250	16	1170	225	111500	1501	41	28000
63-125	30	3900	596	218400	2919	96	36470
<63	19	1730	403	137500	2294	113	23080

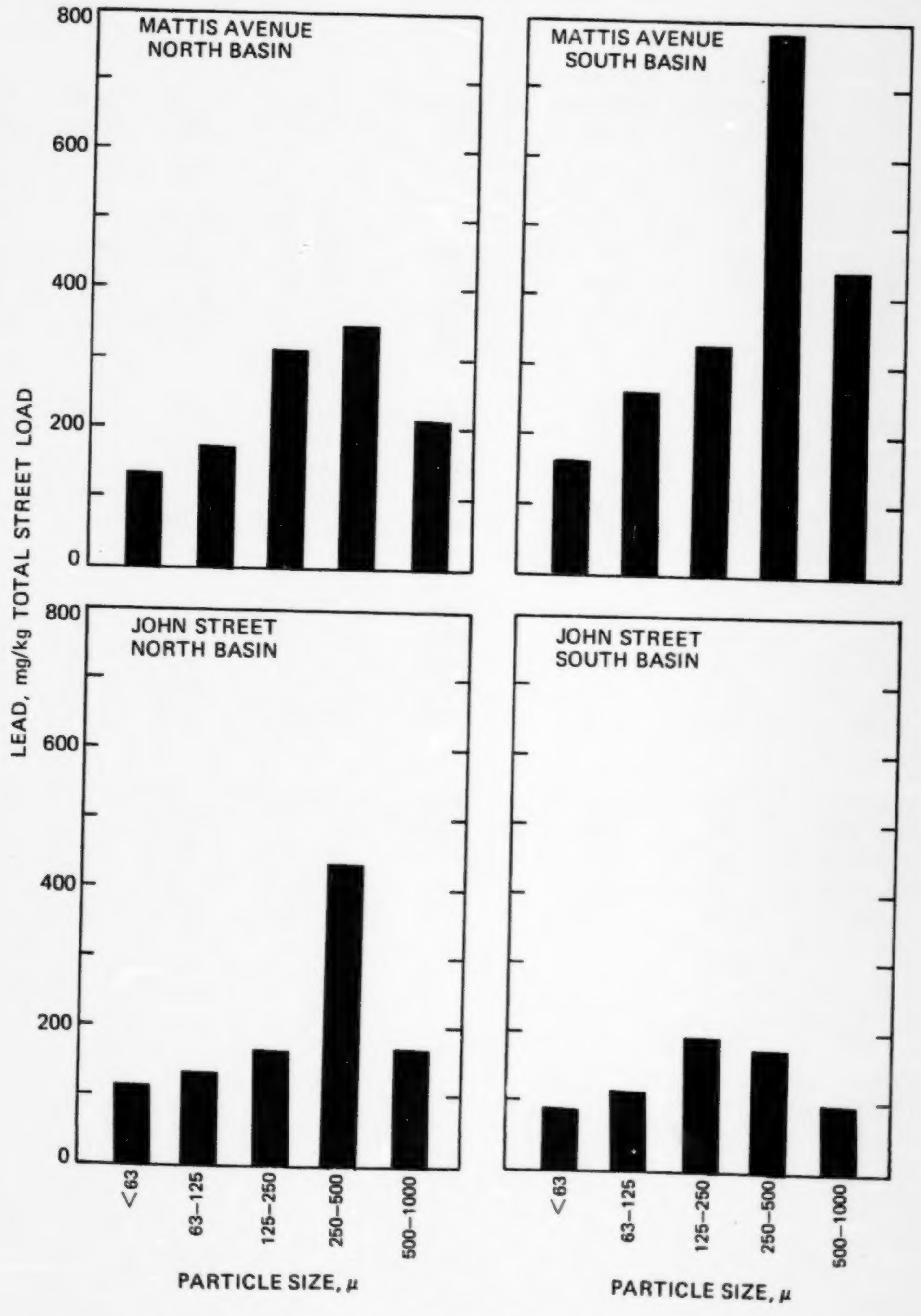

Figure 6.6 Lead load per unit street load by particle size group

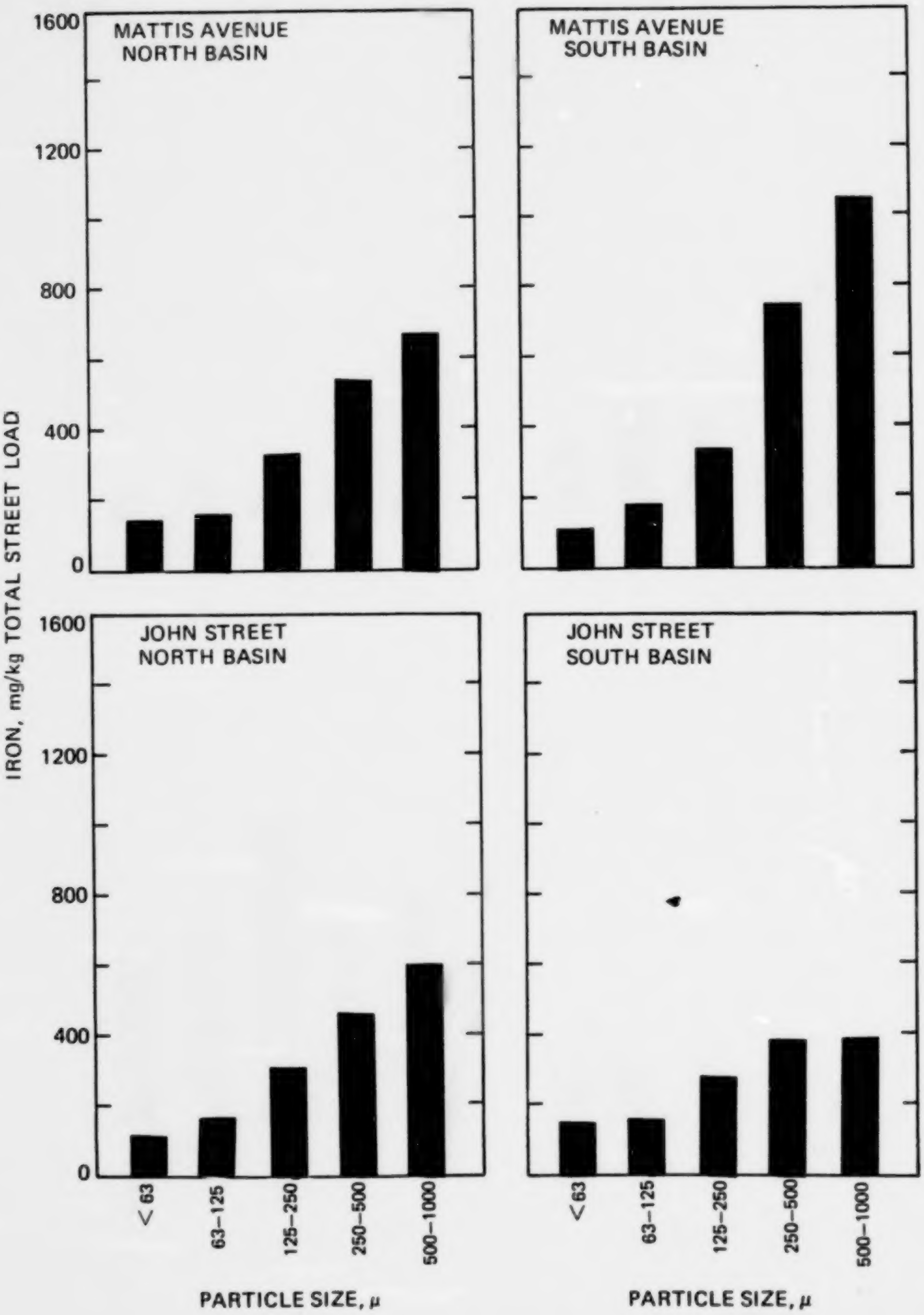

Figure 6.7 Iron load per unit street load by particle size group

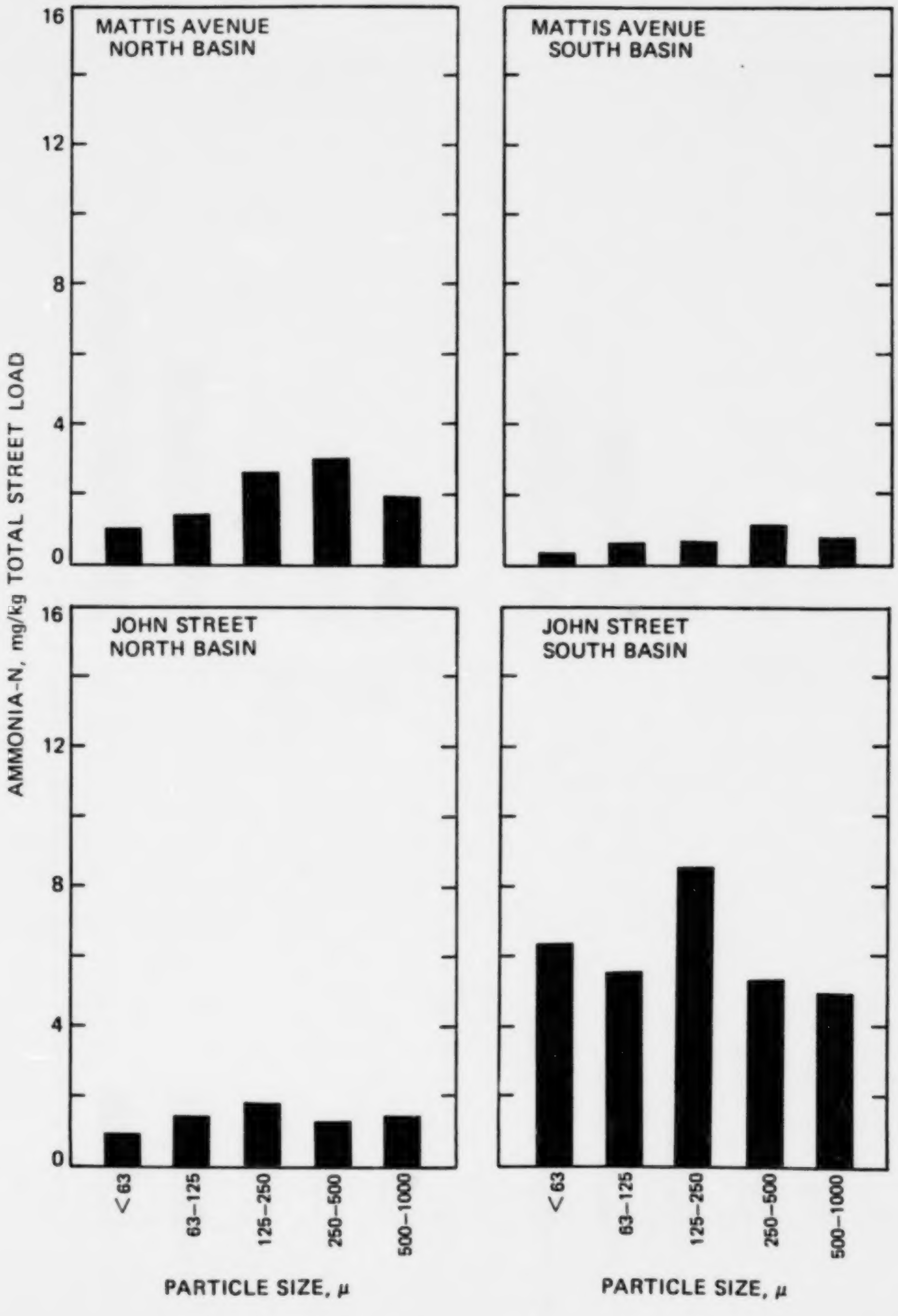

Figure 6.8 Ammonia-N load per unit street load by particle size group

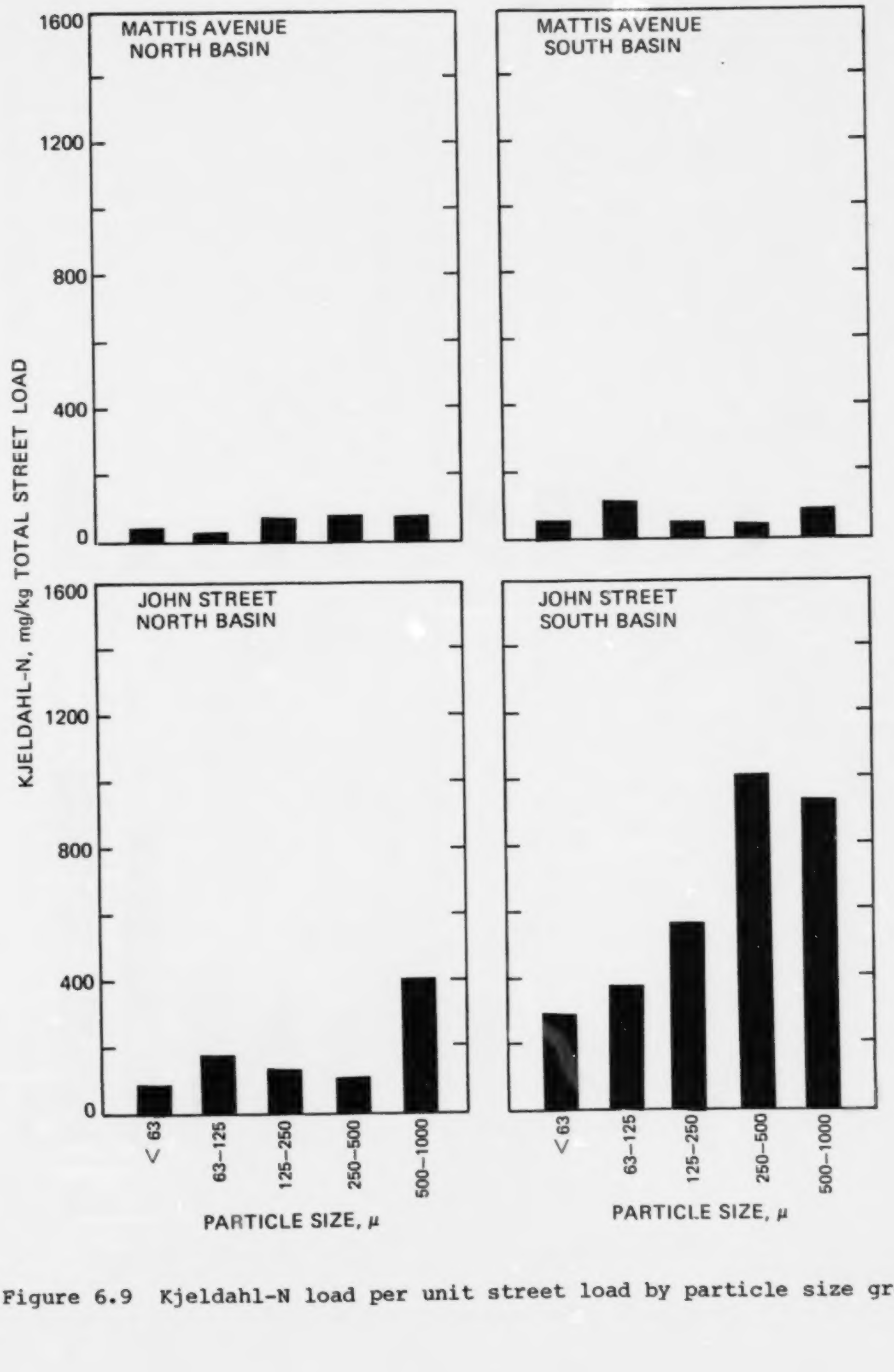

Figure 6.9 Kjeldahl-N load per unit street load by particle size group

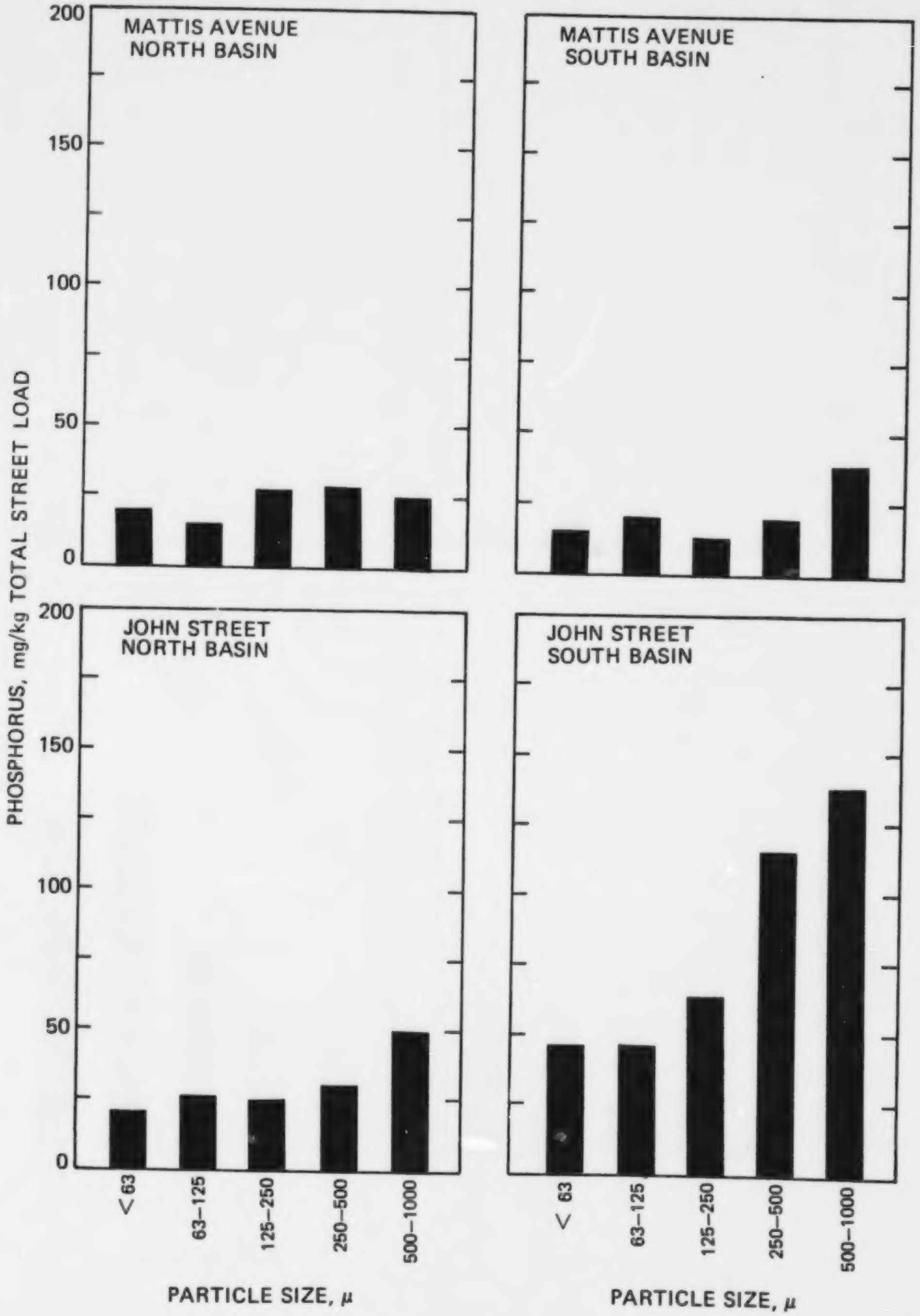

Figure 6.10 Phosphorus load per unit street load by particle size group

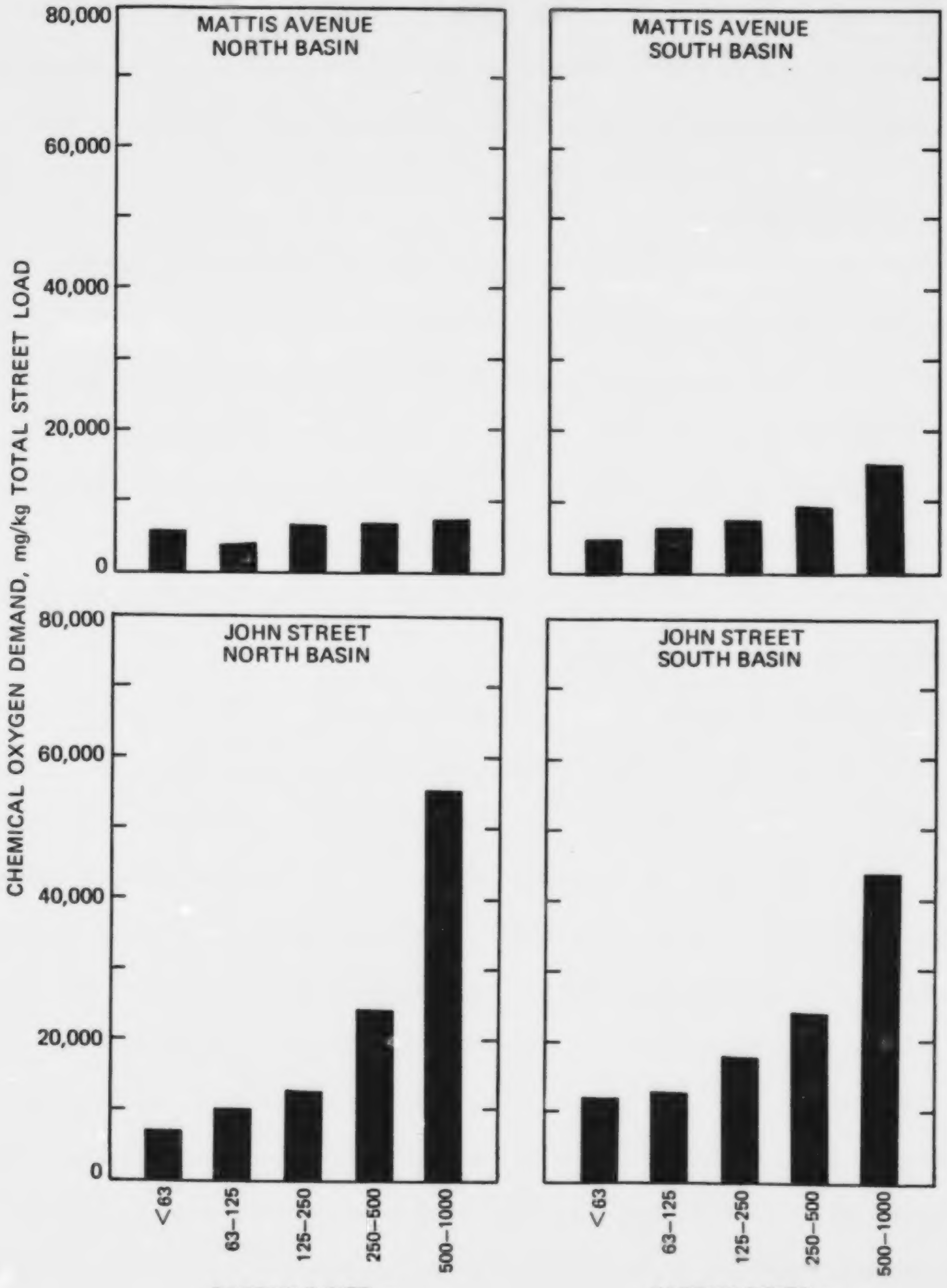

Figure 6.11 Chemical Oxygen Demand load per unit street load by particle size group

about 55-60% of the total street load on any basin, they certainly comprise the greatest part of the material actually available for washoff under any but the most extraordinary circumstances. Therefore it is reasonable to use this calculated value to represent the constituent load on a basin.

Sweeper Performance

The performance of a street sweeper can best be determined by comparing street load measurements made before and after sweeping. When the particle size distributions are known, removal efficiencies can be calculated not only for total solids but also for the different particle size groups which make up the street load. When coupled with results of chemical analysis of different size groups for concentrations of constituents in dry solids, the amounts of particular constituents removed by sweeping can be calculated.

The results presented here are based on data gathered in 1981, when sampling of the total loads on the experimental basins before and after sweeping became a routine feature of the program. In figure 6.12, initial street loads were plotted against remaining loads for all days of sweeping on all four basins during 1981. There were eleven such days for Mattis North, ten for John South, and five each for Mattis South and John North. The data were divided into two groups. The Mattis North results were treated separately from the others because the values for initial and remaining loads there were much greater than from the other basins. The results from the remaining three basins were grouped together. Linear regressions were run on the two groups of data and the resulting lines were plotted on figure 6.12. The characteristics of the regression lines are listed in table 6.5. It must be acknowledged that the relationships

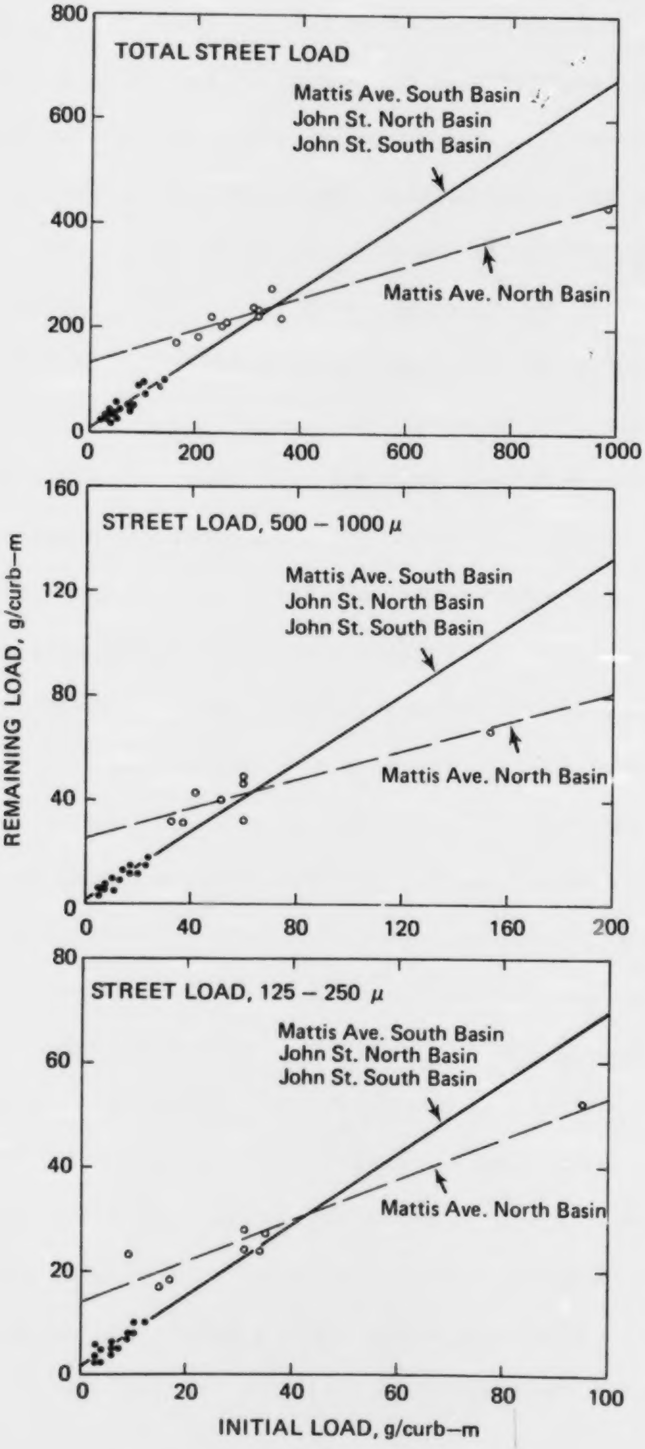

Figure 6.12 Sweeper performance

described by the regression lines are pertinent only to the ranges of values which could be expected as initial loads on the various basins. Nevertheless, comparison of the slopes of the lines suggests that sweeping performs a appreciably poorer job of total street load removal in Mattis North than in the other basins. The ranges of initial load values, in g/curb-m, from which the sweeper performance relationships were derived are as follows: John North, 42-73; John South, 26-70; Mattis South, 90-139; and Mattis South, 166-367, with one extreme value of 988 g/curb-m.

In the plot for total street load in Figure 6.12, it is evident that there were some instances when the load remaining after sweeping was greater than the initial load. This occurred occasionally on each basin when initial loads were relatively low. Part of this phenomenon may be due to inherent error in the sampling procedure, since each street load determination is accurate only within a range of 15-25% around the value. However it is also characteristic of a mechanical street sweeper not to remove much material when the load is low. In fact, by passing over a lightly loaded street and loosening material adhering to the surface, a mechanical sweeper may make available more material than it removes.

The expression of sweeper performance by particle size is a necessary step in evaluating the potential of a sweeper to reduce the load of any constituent on a basin. A conventional mechanical sweeper such as that used in this study does not demonstrate a constant removal through all particle sizes. It is expected instead to show a high removal for large particles which gradually diminishes to a low removal for fine particles. The skill and judgment of the sweeper operator and the magnitude and distribution of the basin load influence the performance of a sweeper on any single day. However over a period of time of sweeping a basin, some pattern of efficiency should emerge.

The data on particle size distribution of street loads determined before and after street sweeping in 1981 were used in analyses similar to that done for total load. The initial and remaining loads on each basin in each particle size range were plotted, the basin results were grouped as before, and linear regressions were run on the grouped data. The results of these regression runs are also included in table 6.5, and plots of the data points and regression lines for two of the size groups, 500-1000μ and 125-250μ, are included in figure 6.12. The important thing to realize about the regression results is that a low value for slope implies good removal, while a high value indicates large load remaining after sweeping compared to initial load. According to table 6.5, sweeping is quite productive for the largest material but declines steadily in productivity with decreasing particle size. The Mattis South-John North-John South combination shows a similar trend in diminishing productivity with decreasing particle size until the last two size groups. The slopes of the regression lines for the 63-125μ and smaller than 63μ material suggest a considerable improvement in sweeper removal. However the R^2 values of the two regressions are quite low also, implying that the representation of the data by the regression lines is not reliable.

The results of evaluating sweeper performance by particle size group can be used to estimate removals of any constituent by sweeping. If all that is known is an approximate street load for a basin prior to sweeping, the particle size distribution of the material and the load of any constituent in the material smaller than 1000μ can be estimated using information from figures 6.4 and 6.6 to 6.11. The sweeper removal of total load can be determined using the curve for that basin in figure 6.12. The expressions for sweeper performance by particle size group from table 6.5 can be used to estimate the removals in each size range, and the remaining loads of street solids in the five smaller size groups can be multiplied by the concentrations shown in table 6.4. These products can be added to give an approximation of the load of the constituent remaining on the basin after sweeping.

As an example, the loading values observed for Mattis South basin on May 4, 1981 were chosen. The initial street load was 139 g/curb-m. Use of figure 6.6 allowed calculation of the load of lead in material smaller than 1000μ as 274 mg/curb-m before sweeping. The characteristic particle size distribution was used to determine fractions of the total load in each size range. The expressions of sweeper performance in table 6.5 were used to estimate the reduction of total load and partial load by sweeping. The partial loads remaining after sweeping were multiplied by the characteristic concentrations for lead shown in table 6.4. The total street load after sweeping was calculated to be 101 g/curb-m, and the load of lead in material smaller than 1000 was estimated at 192 g/curb-m. The actual observations of the street load before and after sweeping on that day showed the total load to have dropped from 139 to 101 g/curb-m and the lead load to have decreased from 141 to 121 mg/curb-m. Certainly the measurements associated with the basins that day are more reliable, but the procedure described here provides acceptable estimates of reduction of loads of total solids and individual constituents due to street sweeping.

Table 6.5. Characteristics of Linear Regressions for Sweeper Removal of Total and Partial Street Load

	Mattis North			Mattis South, John North, John South Combined		
	Slope	Intercept	R^2	Slope	Intercept	R^2
Total Load	.31	131	.97	.67	8.1	.91
Partial Load by Size Range (μ)						
>2000	.15	54	.88	.53	1.2	.75
1000-2000	.26	20	.82	.65	0.7	.92
500-1000	.28	25	.89	.66	1.1	.95
250-500	.39	23	.97	.64	2.6	.96
125-250	.39	14	.96	.68	1.5	.89
63-125	.51	4	.97	.53	1.3	.53
<63	.56	6	.83	.34	2.9	.46

Sweeping Production Functions

During the periods of experimental street sweeping in this project only two sweeping frequencies, once per week and twice per week, were tested. However, an expression describing the probable effect of any sweeping frequency on the street load of a basin may be developed from the information generated to this point. Such an expression is called a production function, and the principal elements required for its development are data on sweeper performance and characteristics of deposition, accumulation, particle size distribution, and constituent concentration in the street load. The production function demonstrates the relationship between different levels of sweeping effort and the removals of any component of the street load, including total material, they can be expected to produce. The application of results from street sweeping cost studies permit the translation of sweeping effort into expense and the subsequent calculation of the total and marginal costs of removing any part of the load of any constituent from the basin.

Sweeping production functions have been developed for total street load for two basins, Mattis North and John North, as examples. The same development could be done for any portion of the total load composed of one or more particle size groups or for any elemental constituent of the street load. The principal inputs to this analysis were the street load deposition and accumulation data from figure 6.3 and table 6.2, and the expressions for sweeper performance shown in figure 6.12 and table 6.5. A key decision was to ignore any possible effect of washoff and to assume instead that street sweeping was the only influence on the street load. This assumption resulted in calculations of load removals for various levels of effort which represent maximum possible performance. Removal of street load by washoff or any other agent during a period of specific sweeping frequency would cause the load removal by the sweeper to be less than the calculated maximum. This would also increase the unit costs for load removed from a basin.

The basic approach in developing the production functions was to determine the total loads removed by different street sweeping frequencies through a season of sweeping. Street sweeping can be done effectively in the Champaign area only about eight months, or 245 days, per year. Starting with the estimated maximum load possible on the basin and a specified sweeping frequency, the sweeper performance expression for the basin was used to calculate the load remaining after a single sweeping. After that, the load accumulation curve for the basins was used to estimate the street load before the next sweeping. The sweeper performance curve was then used again to calculate the load remaining after the second sweeping. These steps were repeated until the point was identified at which the amount removed by each sweeping at the stated frequency was equal to the amount accumulating between sweepings. This amount of street load was associated with that sweeping frequency on that basin and was multiplied by the number of sweepings that frequency would constitute in a 245-day period to produce the total load removed from the basin during a season at the sweeping frequency. This process was repeated for several other frequencies. Determination was also made of the sweeping frequency beyond which no increase in sweeping effort could produce an increase in load removal. The total load removed from the basin at this critical frequency was considered the maximum possible load removal.

The production functions for Mattis North and John North are shown in figure 6.13. The horizontal axis represents sweeping frequency, ranging from zero times per season to once per day. The vertical axis represents the percentage of the maximum possible load removal which can actually be removed under any sweeping frequency. Obviously there are large differences between the curves for the two basins. The most significant difference is that for Mattis North, sweeping more often than at a three-day interval results in no additional load removal through a season; while for John North, sweeping more often than once per day can still produce an increase in total load removal for a season. The frequency beyond which no additional load removal over a season can be expected is twice per day for John North. The maximum possible load removals do not appear in the figure but they also are quite different: 8500 g/curb-m for Mattis North, 3400 g/curb-m for John North. These differences are due mainly to characteristics of street loading and physical configuration of the basins discussed earlier.

A summary of street sweeping costs assembled by IEPA[11] was the source of unit costs of sweeping used in this analysis. Costs were deter-

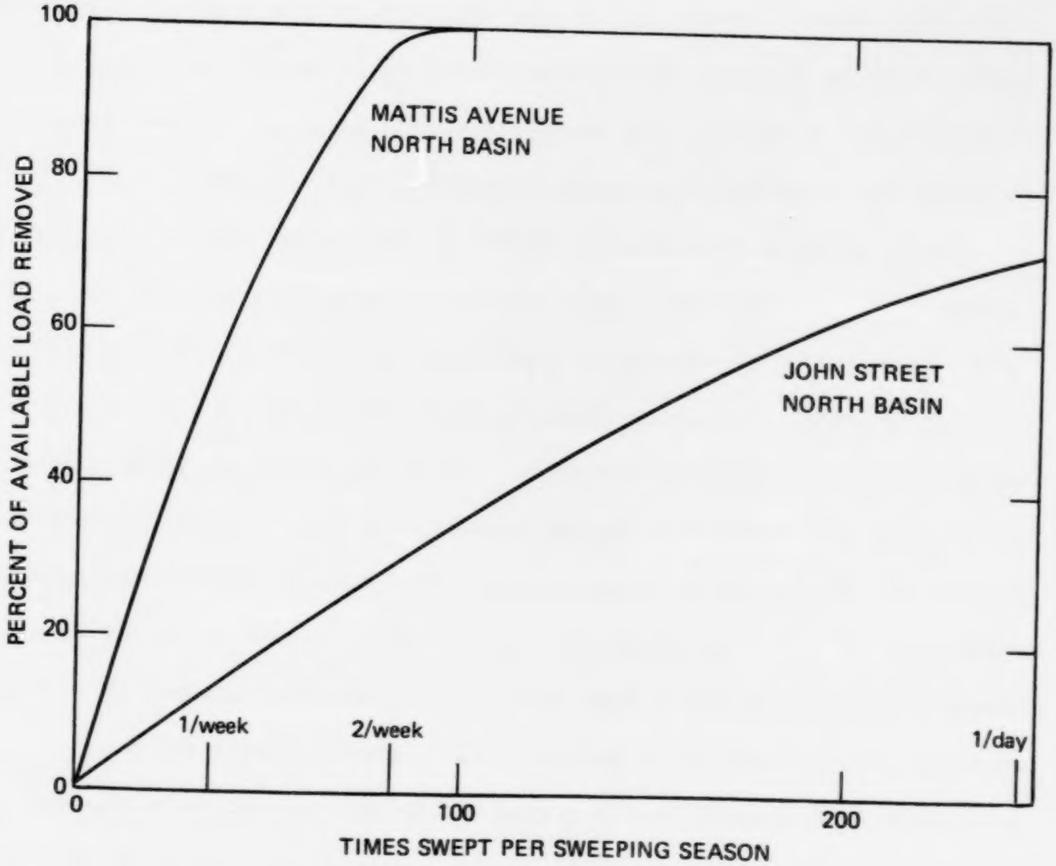

Figure 6.13 Sweeping production functions - total street load - Mattis North and John North

mined specifically for the project work and generally for the community effort. Summaries of a similar sort were done for each of the NURP projects involving street cleaning. In IEPA's summary, four categories of costs were identified: Personnel Services, consisting of salaries, insurance, fringe benefits, and associated costs for both operation and supervision; Indirect, representing administrative and support services; Contractual Services, containing landfill user charges and equipment repairs; and Commodities, including fuel, oil, supplies, and parts, such as replacement brooms for the sweeper. Since depreciation of equipment is not counted in the City of Champaign's operations budget, it was not included in the calculation of unit costs.

The breakdown of sweeping costs into the four categories for the project and the community is shown in table 6.6. The total of $3174 for the project represents the costs only of experimental sweeping and not the special basin cleanups requested occasionally during the two years of monitoring. The cleanups were considered to be inconsistent with routine sweeping practice and therefore inappropriate for inclusion in the unit cost calculation. With a total length of 278 curb-miles swept in the project, the unit cost was $11.42 per curb-mile.

Fiscal year 1981 records were the source of the costs by category for the municipal sweeping program. Under commodities, 28% of the annual cost went for fuel and oil, 39% for replacement brooms, and 32% for other parts and supplies. Under contractual services, 47% of the cost was due to landfill charges and 48% to equipment repairs. Altogether $53,445 was spent on the municipal street sweeping program in FY 81. No accurate record of distance swept had been kept by the city, so minimum and maximum distances of 3833 and 4846 curb-miles, respectively, were estimated by public works

Table 6.6. Street Sweeping Costs in Champaign, Illinois

Category	NURP Project	Municipal Program FY 81
Personnel Services	$1,676	$30,769
Indirect	48	1,200
Commodities	1,256	9,389
Contractual Services	194	12,087
TOTAL	$3,174	$53,445
Curb-miles swept	278	est. minimum 3833 est. maximum 4846
Sweeping Cost ($/curb-mile)	11.42	maximum 13.94 minimum 11.03

personnel. This permitted the calculation of minimum and maximum unit costs of $11.03 and $13.94 per curb-mile. The inclusion of equipment depreciation in the calculation would have raised the unit cost by one to two dollars per curb-mile. These values fall comfortably into the range of $10-25 per curb-mile determined by the nationwide survey of sweeping costs. An average sweeping cost of $12.50 per curb-mile, or $7.70 per curb-kilometer, was used in the subsequent development of the cost function.

Figure 6.14 indicates for each basin the cost of achieving a particular level of street load removal. The horizontal axis is the same as the vertical axis in figure 6.13, the percentage of the maximum possible load removal which can be accomplished by some sweeping effort. The vertical axis represents the level of sweeping effort not in terms of frequency but in terms of cost, specifically in dollars spent per curb-kilometer in the basin. This construction was adopted so that the two curves could be

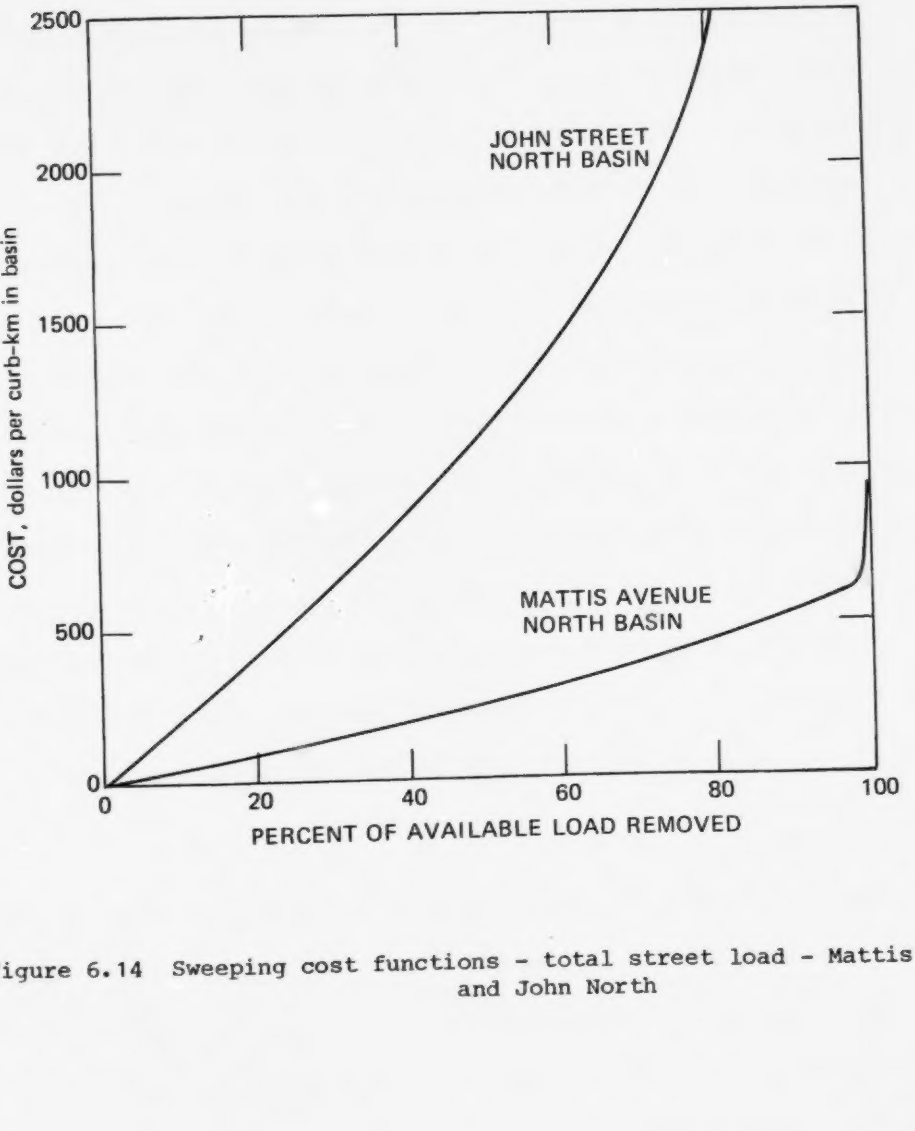

Figure 6.14 Sweeping cost functions - total street load - Mattis North and John North

plotted together. Because of the disparity in average street loads and length of street in the two basins, a figure plotting total load removal against total expenditure would be a less apt comparison. Figure 6.14 indicates that for 50% removal of the maximum possible load removal on Mattis North, about $250 would have to be spent on sweeping for every curb-kilometer in the basin. Since the total curb length in Mattis North is 1.86 curb-km and the maximum possible load removal is 8500 g/curb-m, this would represent a removal of 7900 kg of street load at a cost of $465, a unit cost of $0.06/kg. A similar calculation for John North, where the 50% removal cost is $1150 per curb-km, the curb length is 7.70 curb-km, and the maximum possible load removal is 3400 g/curb-m, which reveals a removal of 13090 kg of street load at a cost of $8860, a unit cost of $0.68/kg.

Finally, however, the most important question with respect to this analysis is whether reduction of street load through sweeping has any observable effect on runoff quality. Unless there is some corresponding reduction in the load of solids or water quality constituents from a swept area, there is no point in determining the cost of removing any amount of any constituent from the basin by sweeping, since whatever would be removed would not be influencing runoff quality. The following section on results of runoff monitoring addresses this point more thoroughly.

WATER QUALITY

The results of water quality analyses will be presented in two ways in the following sections. The first method has been called a parallel analysis since data is collected from two basins, an experimental and a control basin, at the same time. The second approach, known as a series analysis, requires only one basin. This basin is operated first under control conditions for a period of time and then under experimental conditions for a period of time.

Parallel Analysis

The parallel analysis requires that two basins are available that have similar hydrologic, hydraulic, loading and washoff characteristics. Considerable effort (described in Section 2) went into the selection of basins that would have these features. The similarity of the basins was further investigated using a simulation model in Section 4. The simulation showed that hydrologically the basin pairs are relatively similar. However, an unexpected hydraulic problem was identified on the John Street basins. Perhaps more significant and totally unexpected was the difference in street dirt accumulation between the Mattis Avenue north and south basins. The authors now feel that the extremely flat slope over much of the Mattis North basin caused more material to be retained on the street surface after runoff events. Since the deposition rate must be nearly the same for each of these basins, the higher minimum loading for Mattis North caused it to have a higher loading at any given time. It is also believed that the east-west orientation of much of the Mattis North basin made it less susceptible to removal of material by wind.

Inherent differences in the characteristics of the basin pairs were overcome to some extent by comparing the basins first during a control period with neither basin swept and then with one basin swept and the other basin unswept. Linear regression lines were fit to each of these conditions for both event mean concentration (EMC) in mg/l and total washoff in grams per curb meter. The regression lines offered a graphic means of comparing the relative basin performances but were not easily summarized. For summary purposes, a normalized ratio of the swept to unswept basin EMC and total load for each constituent was also developed.

Mattis Avenue Basins--

The greatest strength of the parallel analysis results from the fact that comparisons are made with the same storm event occurring on both the control and experimental basins simultaneously. To achieve this comparison, however, the total sampling period must be broken into three distinct sets. These are: 1) both basins unswept, 2) south basin swept and north basin unswept, and 3) north basin swept and south basin unswept. This fragments the data base, resulting in a small number of events for each condition. Since two sets of equipment must function properly to provide one set of data for the pair of basins, it is likely that the data sets will be further reduced due to equipment failure.

EMC values are presented in figures 6.15 through 6.18 to illustrate the size of the individual data sets and the scatter of the data. Once weekly and twice weekly sweeping showed no difference in results and were combined in all of these analyses. Since the Mattis South data are plotted on the ordinate, the Mattis South swept line should lie below the unswept line if sweeping was effective in reducing concentrations of the subject constituent. Conversely, the Mattis North swept line should lie above the unswept line if sweeping was effective. It seems clear that no conclusions can be drawn from this analysis. For the constituents shown, the most consistent feature is the Mattis North swept line below the unswept line. This would indicate that sweeping of Mattis North increases the EMC of the constituents shown. The Mattis South line often intersects the unswept line and is generally not significantly different.

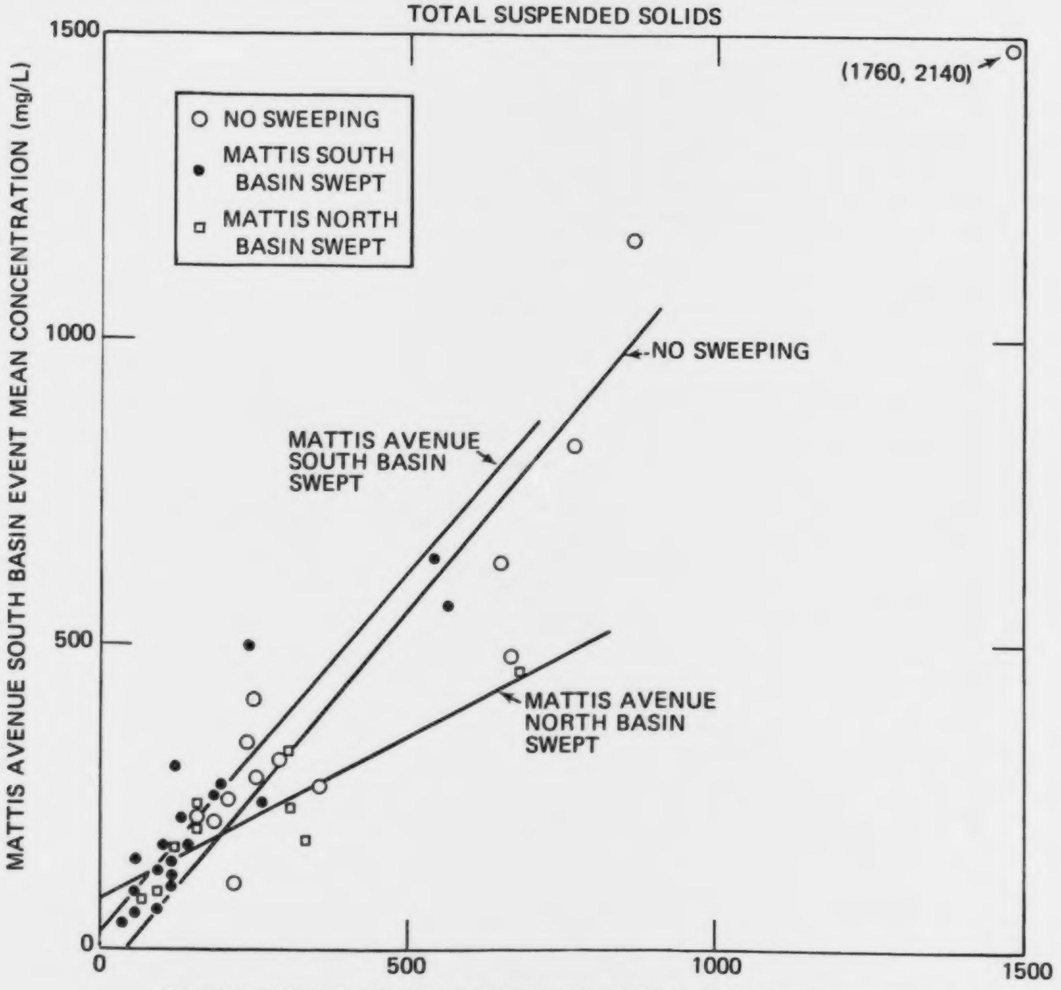

Figure 6.15 Event mean concentration of TSS for Mattis basins

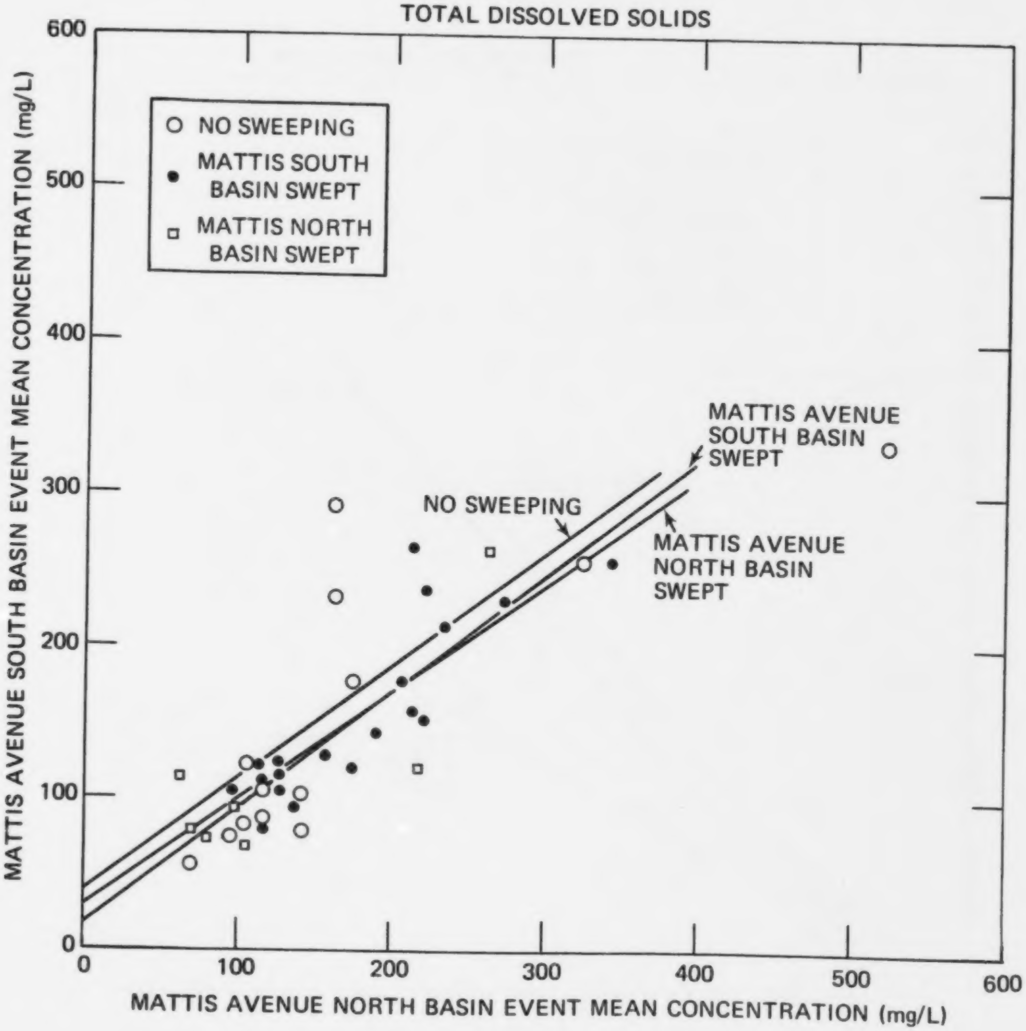

Figure 6.16 Event mean concentration of TDS for Mattis basins

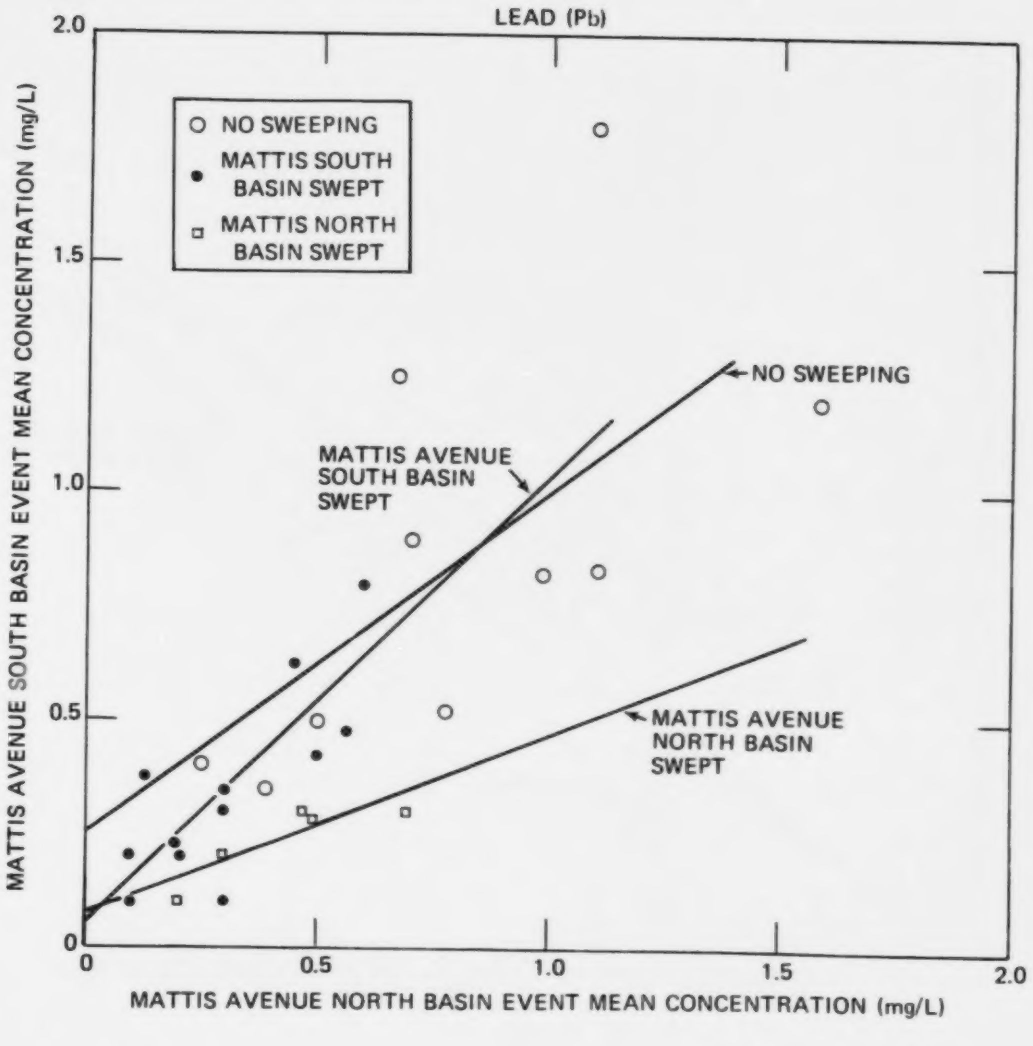

Figure 6.17 Event mean concentration of Lead for Mattis basins

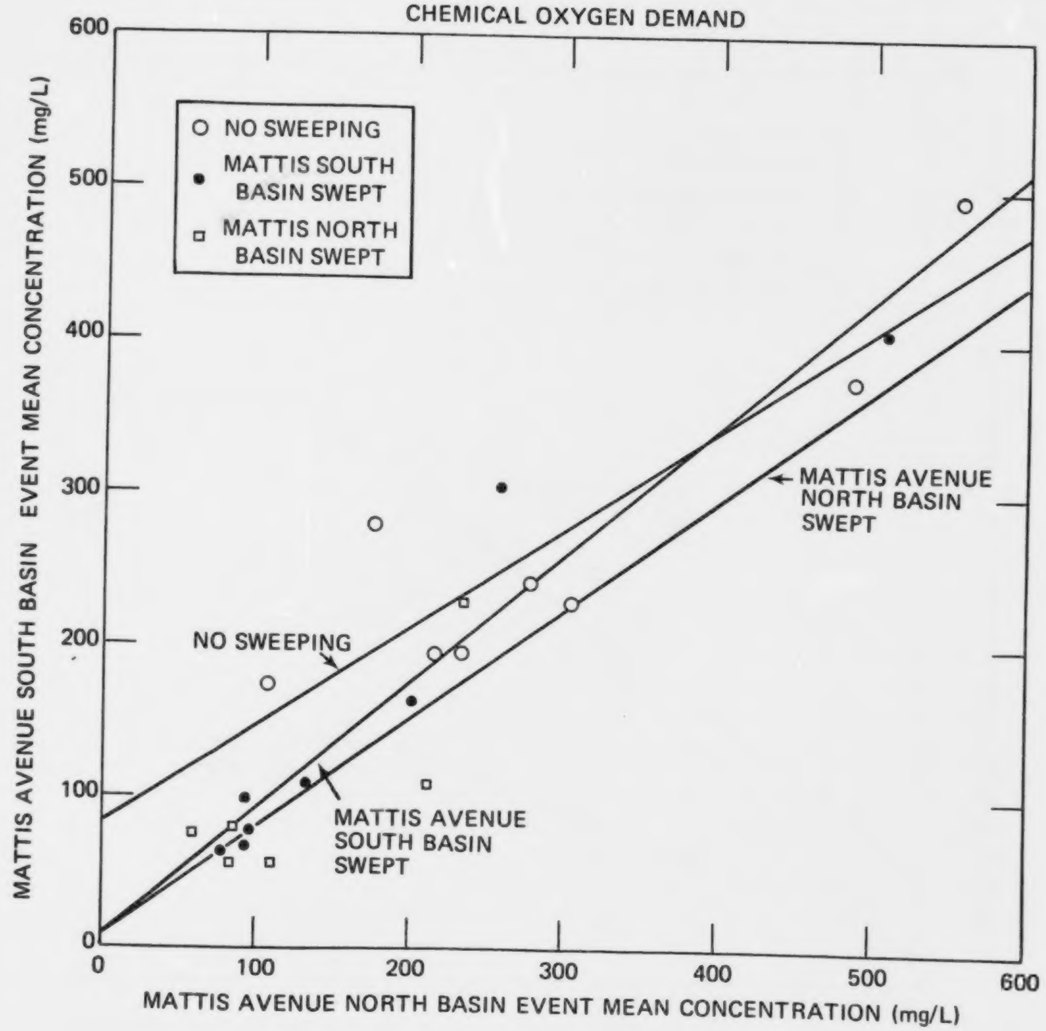

Figure 6.18 Event mean concentration of COD for Mattis basins

As further illustration of these data sets, total loads for the same four constituents are presented in figures 6.19 through 6.22. While one might be tempted to conclude that sweeping Mattis South is effective for TDS and COD, the correlation is low in the first case and one point has an extreme effect on the line in the second. Mattis North again displays a consistent trend toward degraded water quality during sweeping. This phenomenon could be related to the actual storm events occurring during the period when Mattis North was swept. Notice in figure 6.19 that although the mean values of the loads are similar for the Mattis North swept events and the unswept period, they are nearly double those of the Mattis South swept events.

In order to summarize much of the data and present results of more constituents, tables 6.7 and 6.8 were developed. These tables present for each basin ratios of the swept to unswept EMCs and total loads. The ratios are shown with and without normalization for the unswept period. A ratio of 1.0 for both basins swept indicates that for the number of events shown, the mean values of the EMC or total load for a particular constituent produced by the basins are equal. This ratio is in turn used to normalize the appropriate value of the swept to unswept ratio. A value of less than 1 for a swept to unswept ratio indicates that sweeping was effective in reducing the subject EMC or total load. The geometric mean was calculated using logs of the constituent ratios. Significance of the ratios using hypothesis testing will be discussed later in this section.

The results of this analysis for table 6.7 tend to support those seen with the regression lines. For the Mattis South swept data, 6 of the 10 normalized ratios for the constituents shown are less than 1, indicating effective street sweeping. The mean for all ten constituents, however, is

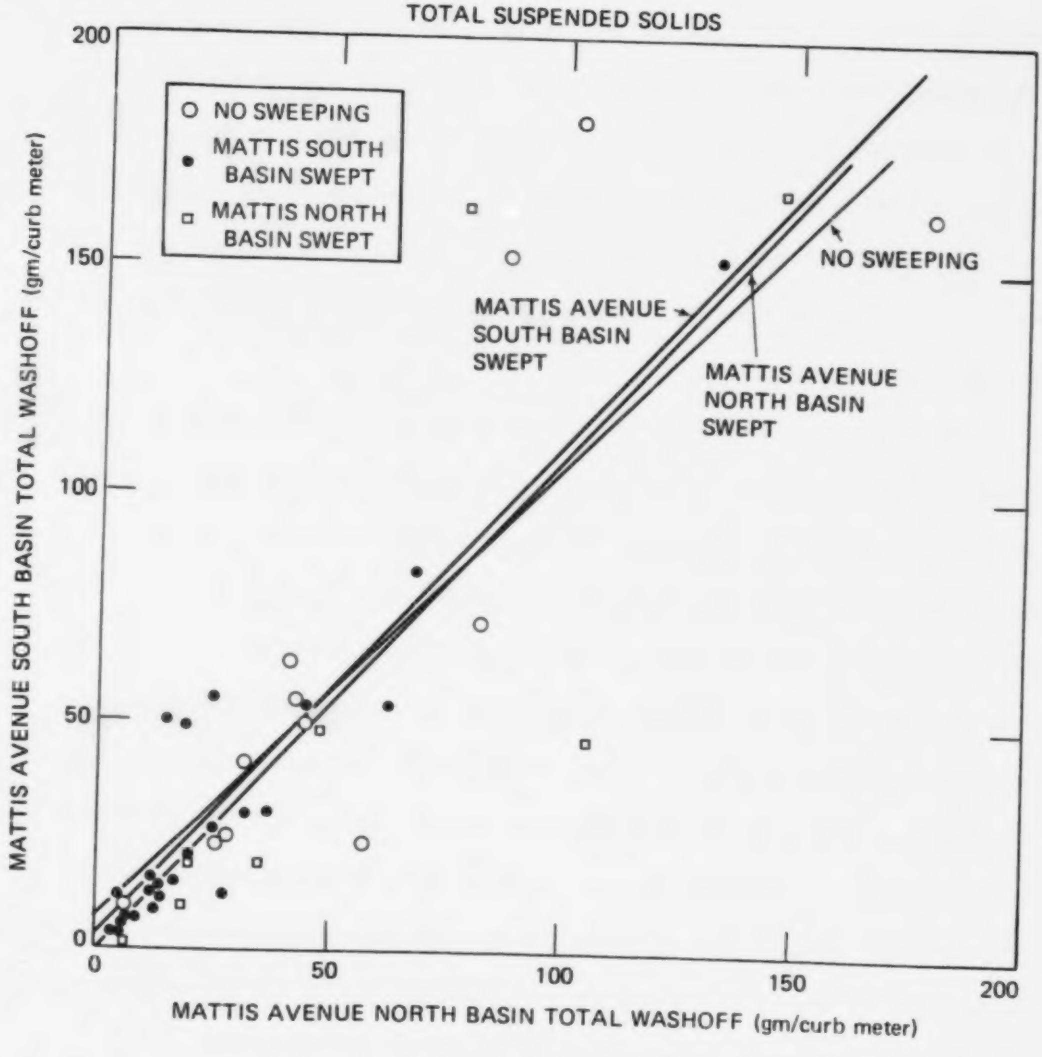

Figure 6.19 Total washoff loads of TSS for Mattis basins

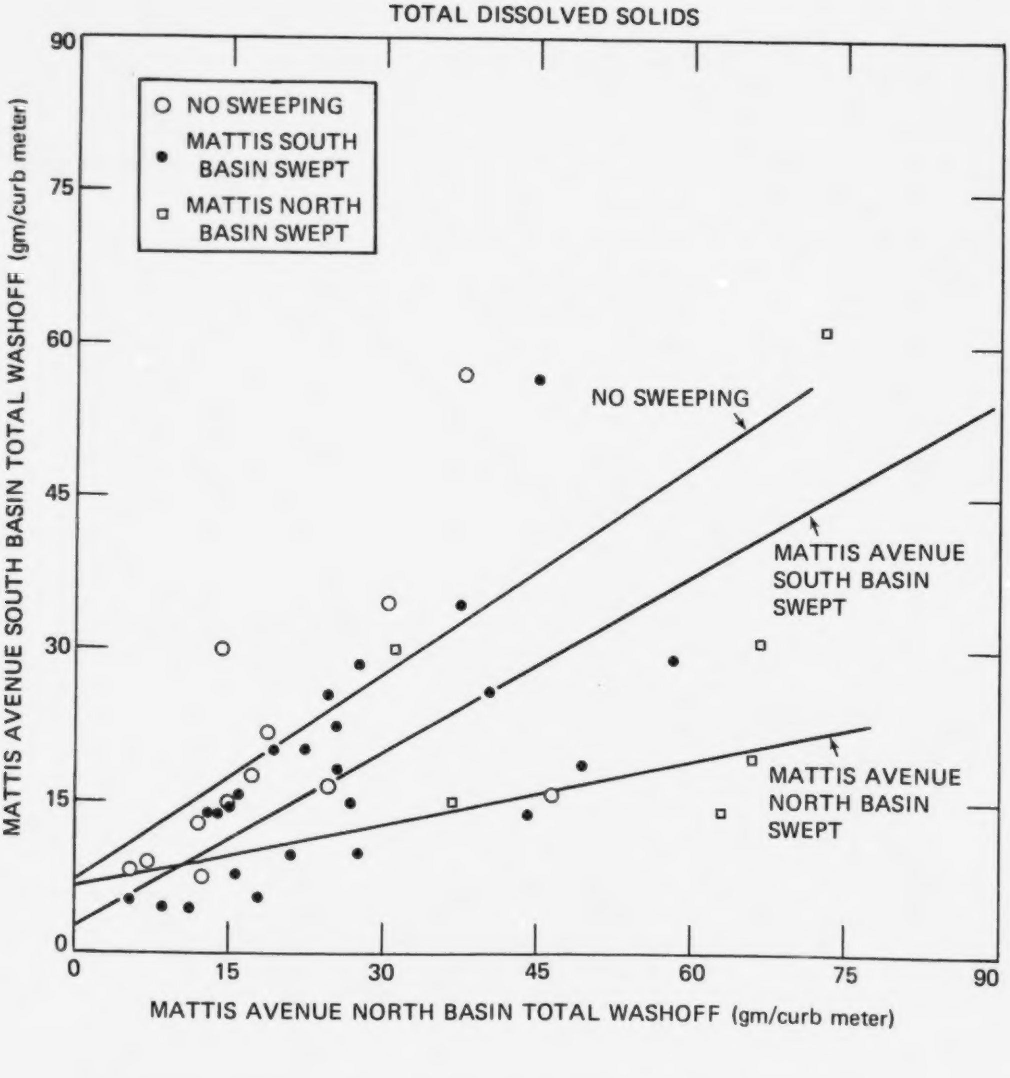

Figure 6.20 Total washoff loads of TDS for Mattis basins

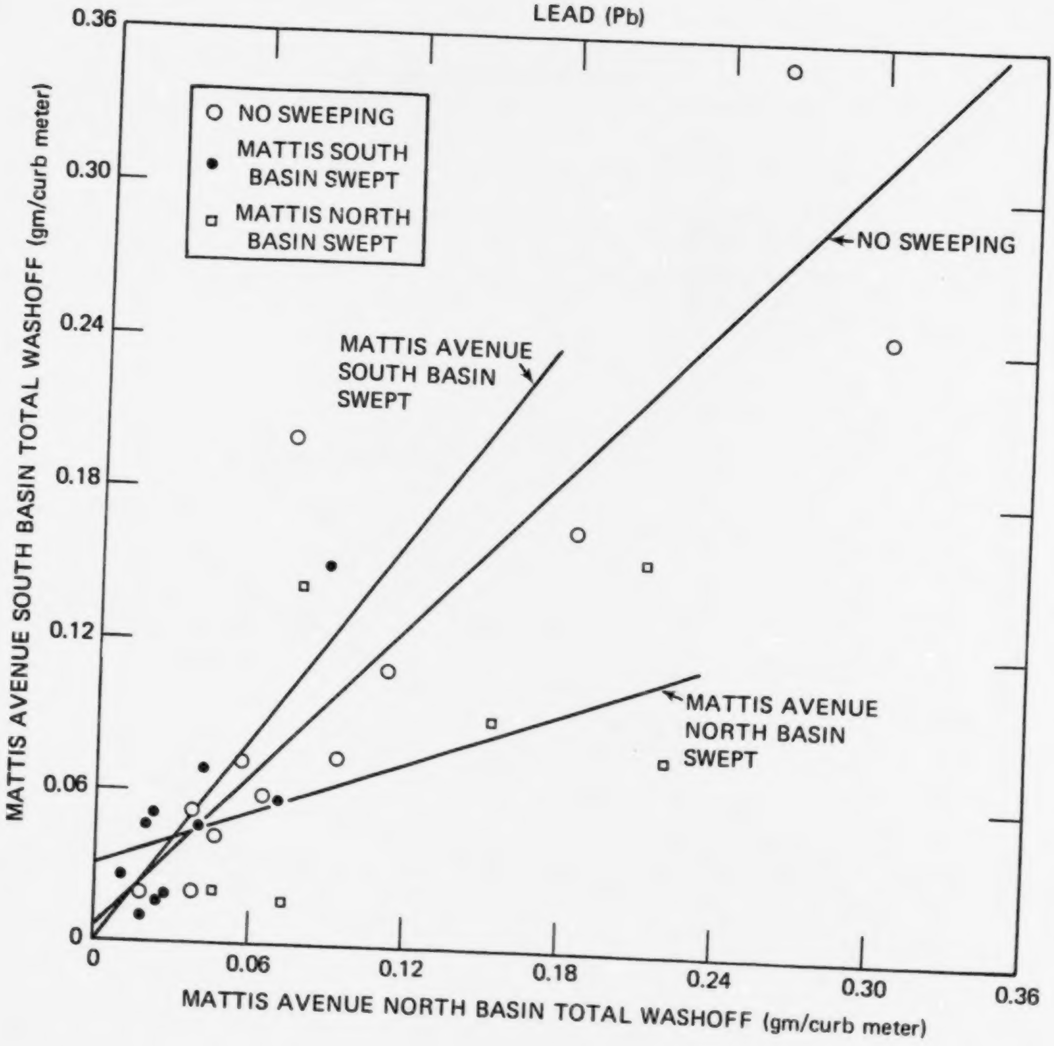

Figure 6.21 Total washoff loads of Lead for Mattis basins

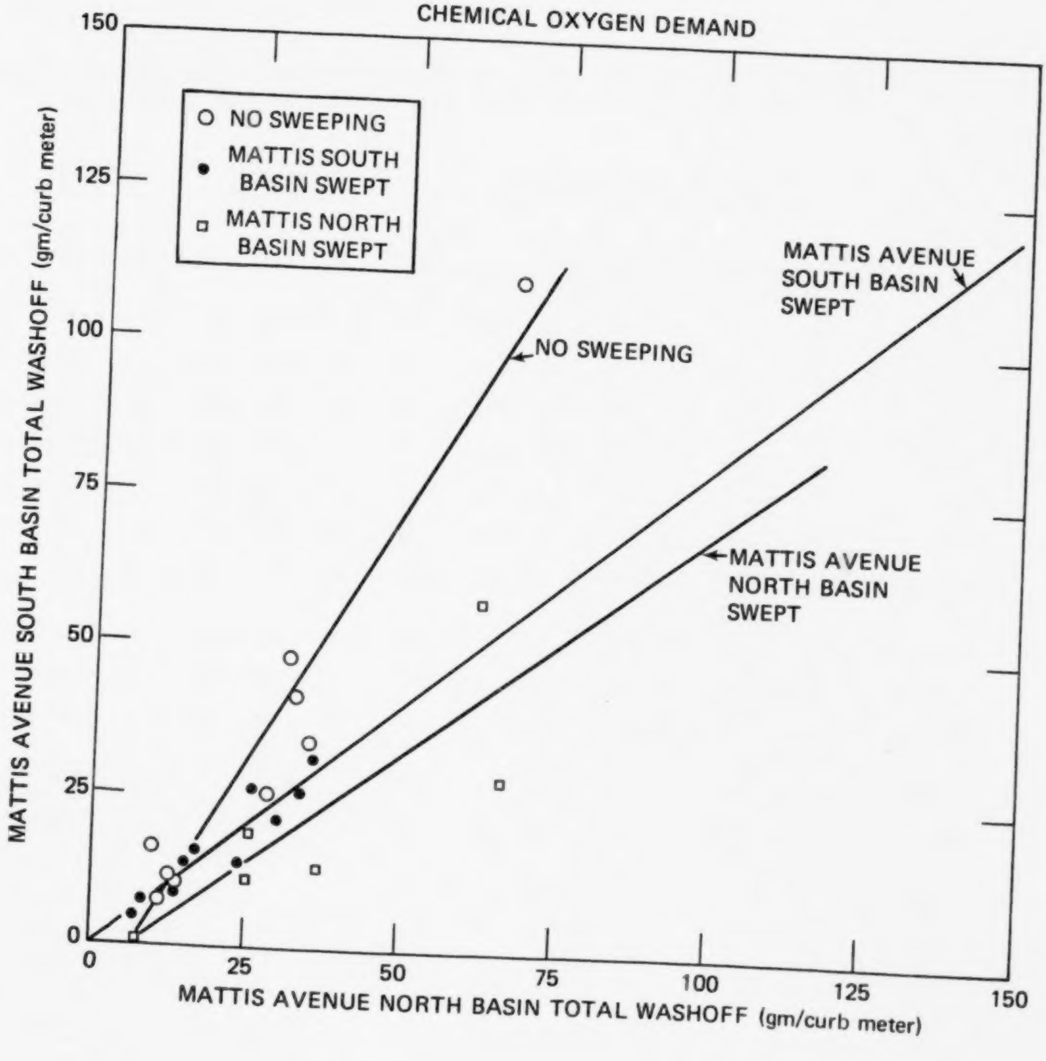

Figure 6.22 Total washoff loads of COD for Mattis basins

Table 6.7 Ratios of Swept to Unswept Event Mean Concentrations for the Mattis Avenue South and Mattis Avenue North Basins.

	MS UNSWEPT / MN UNSWEPT			MS SWEPT / MN UNSWEPT				MN UNSWEPT / MS UNSWEPT			MN SWEPT / MS UNSWEPT			
	#	MEAN	S.D.	#	ACTUAL MEAN	S.D.	NORMAL MEAN	#	MEAN	S.D.	#	ACTUAL MEAN	S.D.	NORMAL MEAN
TSS	13	1.11	.32	19	1.36	.50	1.23	13	1.00	.39	8	1.00	.40	1.00
TDS	13	.93	.34	20	.87	.15	.94	13	1.18	.33	7	1.12	.43	.95
Lead	9	1.28	.73	10	1.14	.43	.89	10	.99	.34	6	1.69	.46	1.71
Copper	11	1.06	.74	11	1.58	2.14	1.49	11	1.29	.69	5	1.37	.53	1.06
Iron	11	1.08	.31	11	1.10	.34	1.02	11	1.01	.31	6	1.57	.66	1.55
COD	9	1.13	.45	8	.88	.16	.78	9	.99	.31	6	1.35	.49	1.36
Nitrate-Nitrite N	9	1.10	.33	9	1.37	1.00	1.25	9	1.02	.44	6	1.17	.71	1.15
Phosphorus	9	1.30	.46	9	1.14	.41	.88	9	.85	.27	6	1.09	.37	1.28
Sulfate	12	1.02	.27	16	.93	.18	.91	12	1.05	.29	7	1.40	.56	1.33
Chloride	12	.79	.26	17	.51	.22	.66	12	1.44	.57	8	2.50	1.18	1.74
G. MEAN		1.07			1.04		.97		1.07			1.38		1.29
S.D.		.16			.34		.24		.16			.37		.28

Table 6.8 Ratios of Swept to Unswept Total Washoff Loads for the Mattis Avenue South and Mattis Avenue North Basins.

	MS UNSWEPT / MN UNSWEPT			MS SWEPT / MN UNSWEPT				MN UNSWEPT / MS UNSWEPT			MN SWEPT / MS UNSWEPT			
	#	MEAN	S.D.	#	ACTUAL MEAN	S.D.	NORMAL MEAN	#	MEAN	S.D.	#	ACTUAL MEAN	S.D.	NORMAL MEAN
TSS	13	1.16	.44	24	1.25	.74	1.07	13	1.02	.53	6	1.61	1.04	1.57
TDS	13	1.05	.48	24	.74	.30	.70	13	1.24	.77	6	2.52	1.35	2.03
Lead	12	1.05	.31	11	1.38	.77	1.31	12	1.04	.35	6	2.17	1.30	2.09
Chloride	13	.84	.47	24	.49	.28	.59	13	1.52	.87	6	4.91	2.33	2.90
COD	10	1.08	.43	10	.81	.16	.75	10	1.12	.61	6	2.84	2.27	2.54
Copper	12	1.03	.46	13	.86	.36	.83	12	1.22	.67	5	1.87	1.50	1.54
Iron	12	1.09	.37	14	.93	.25	.84	12	1.04	.41	6	2.15	1.64	2.07
Nitrate-Nitrite N	10	1.07	.46	11	1.11	.72	1.04	10	1.31	1.06	6	.95	.42	.72
Phosphorus	10	1.23	.46	11	.97	.15	.79	10	.99	.60	7	1.84	1.61	1.85
Sulfate	12	1.14	.55	18	.74	.34	.65	12	1.16	.76	8	3.08	1.59	2.65
G. MEAN		1.07			.89		.83		1.16			2.18		1.88
S.D.		.11			.27		.21		.16			.93		.76

.97 indicating very little effect. For the Mattis North swept data, 9 of the 10 normalized ratios are greater than 1, indicating an increase in EMC values during sweeping. The overall mean normalized ratio for the 10 constituents shown is 1.29 with a standard deviation of .28.

The total load values in table 6.8 show a reduction in load for 7 of 10 constituents when the Mattis South basin is swept, with an overall normalized mean of .83. Data for the Mattis North basin swept confirm those shown using EMC. The number of ratios greater than 2 indicate that a number of very high total loads were generated during this period.

John Street Basins--

Data for the John Street basins are presented in the same format as the Mattis Avenue basins. The factors that cause fragmentation of the data sets discussed for the Mattis Avenue basins had serious implications for the John Street data. During the period of time in which John South was swept, both the primary and back-up samplers for John South malfunctioned. Repairs had to be made by the factory and samples could not be obtained on John South for six weeks. This occurred during a late summer period that produced most of the storms for the John South swept data set. Other data-related problems reduced the data set for John South swept to 3 points. For this reason the points will be shown on the following figures, but no regression line will be drawn.

Figures 6.23 through 6.26 present the EMC data for four constituents to illustrate typical spread and size of the data sets. The same constituents, TSS, TDS, lead, and COD used for the Mattis Avenue basins are presented here. The results are as contradictory as were those for the Mattis Avenue basins. Since John North is plotted on the ordinate, the John North

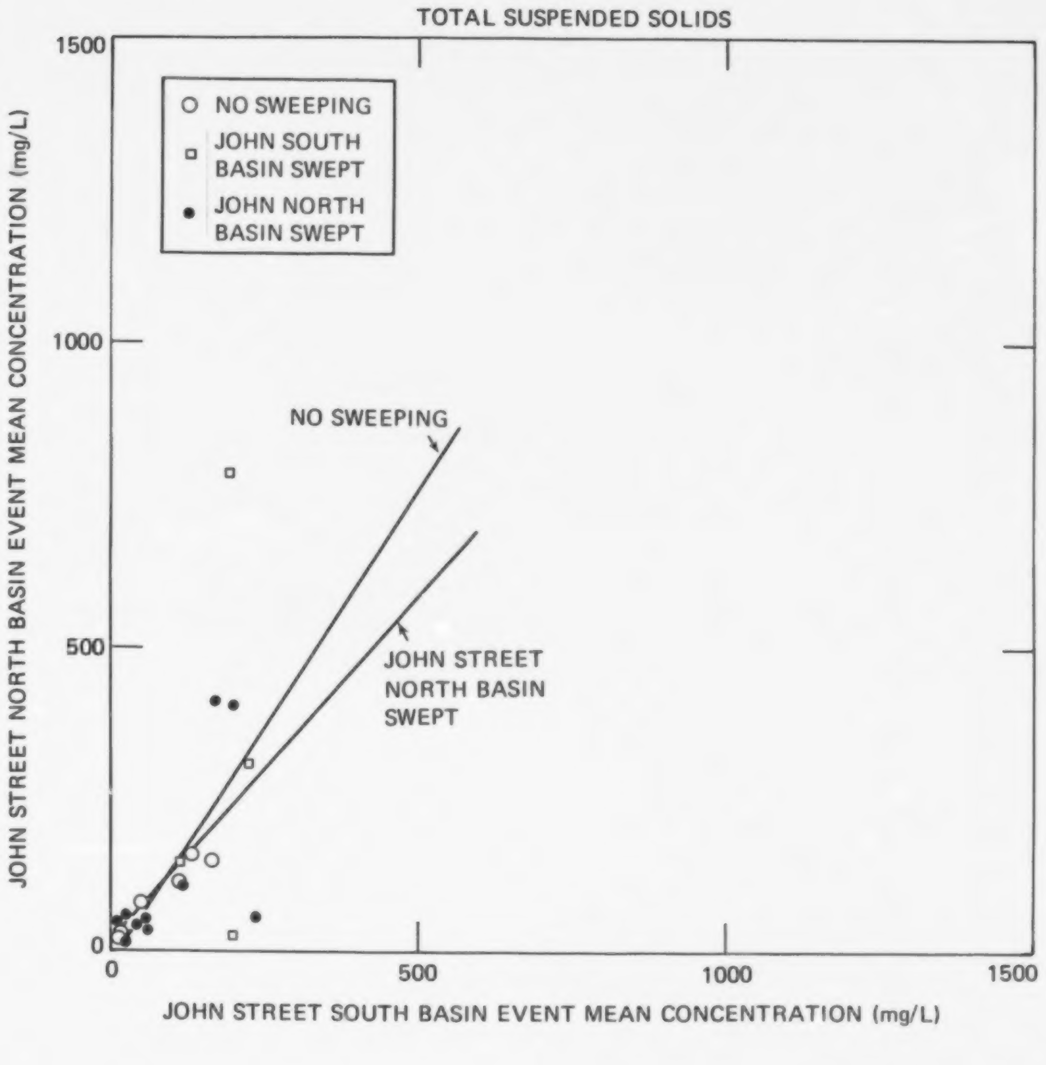

Figure 6.23 Event mean concentration of TSS for John basins

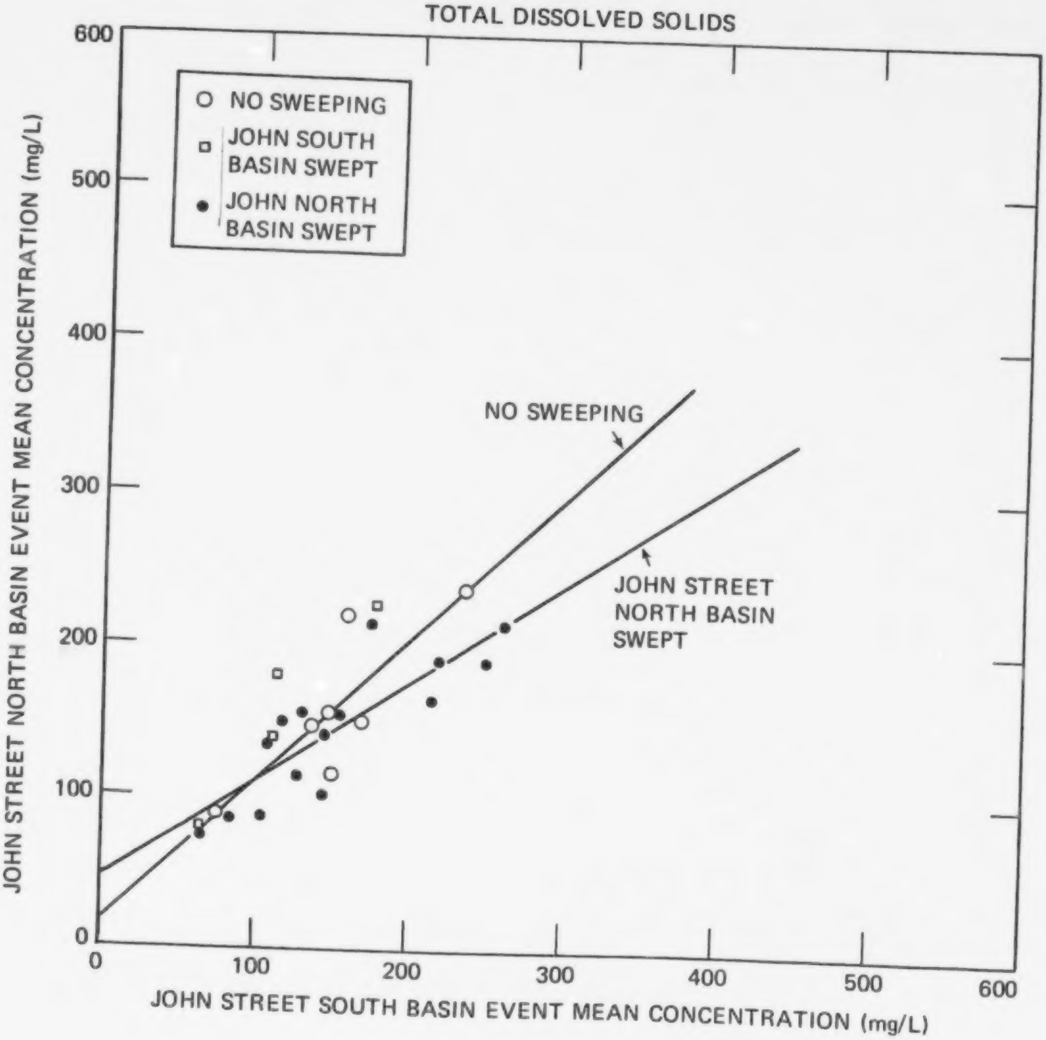

Figure 6.24 Event mean concentration of TDS for John basins

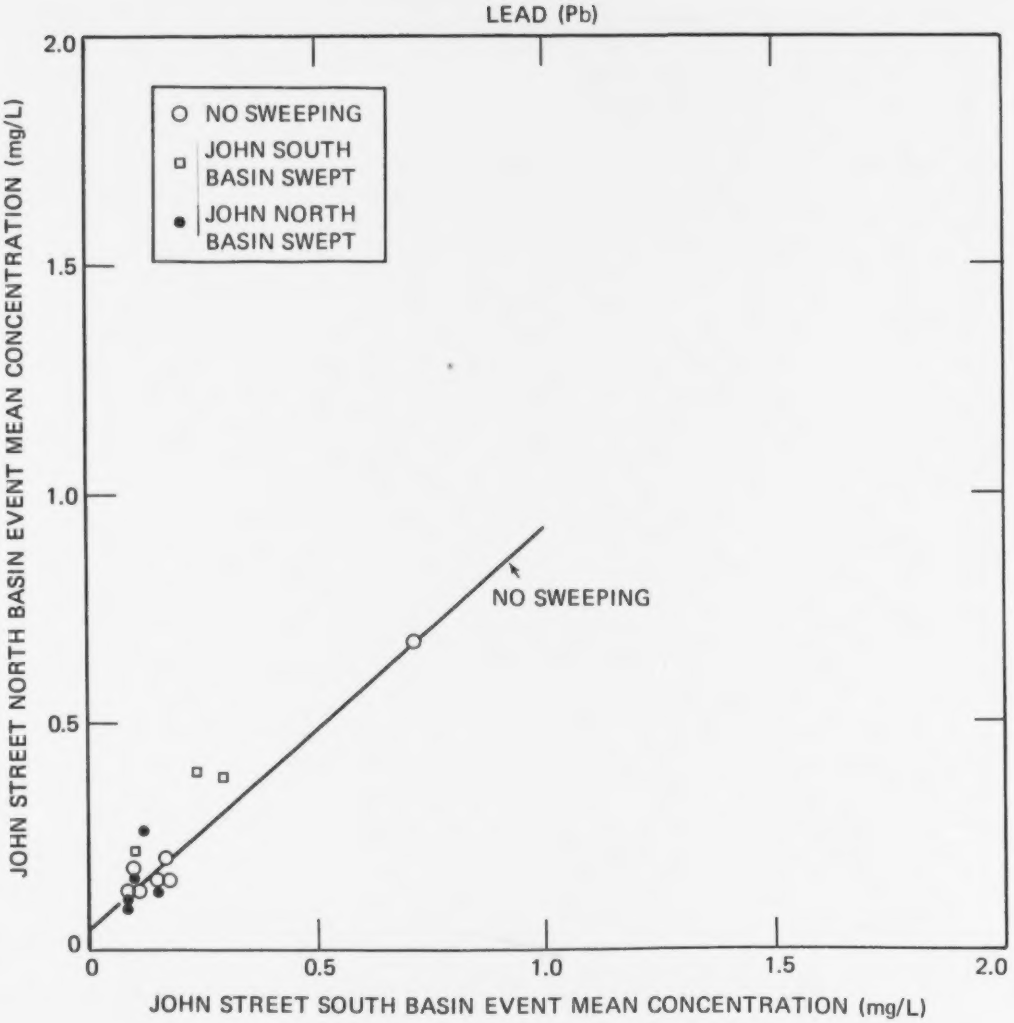

Figure 6.25 Event mean concentration of Lead for John basins

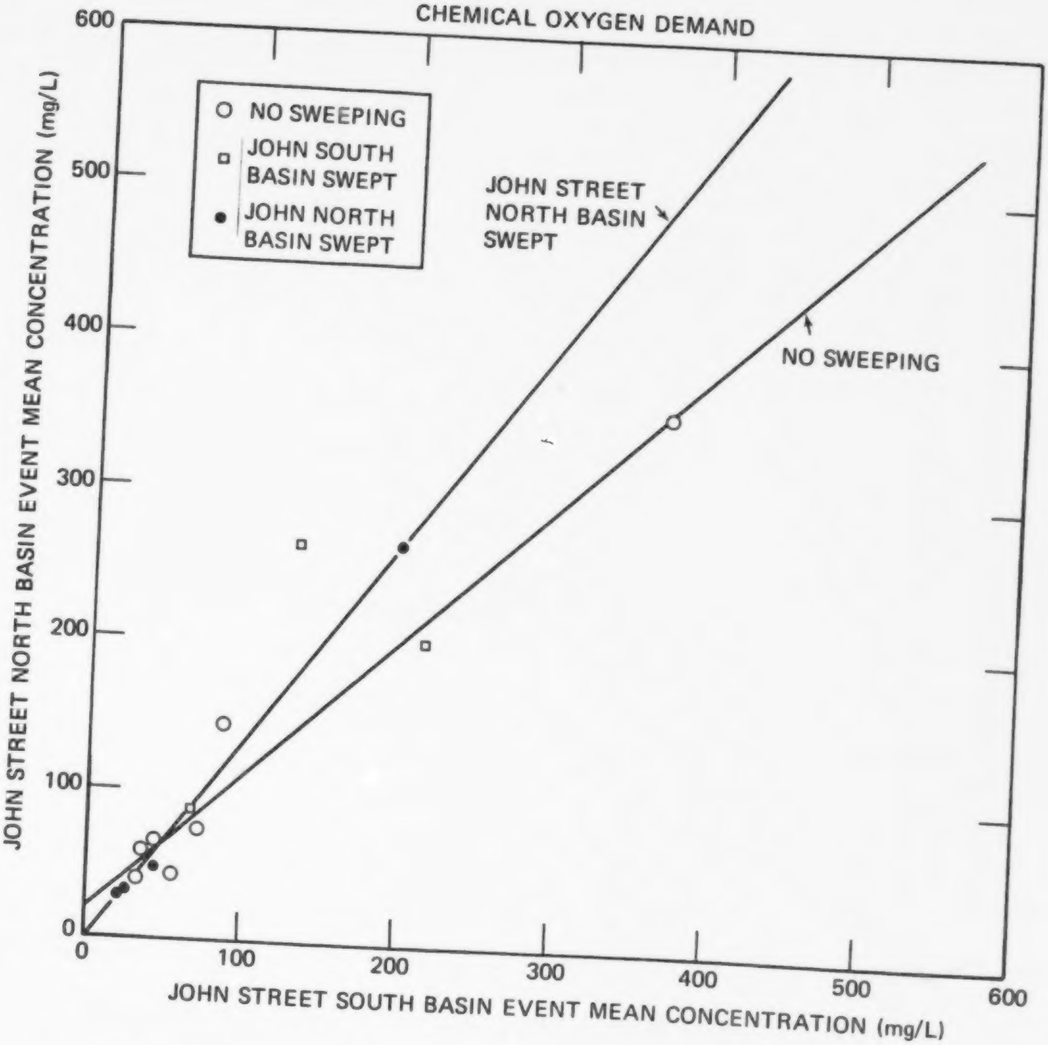

Figure 6.26 Event mean concentration of COD for John basins

swept line would appear below the unswept line if sweeping reduced the subject EMC. This is generally the case for TSS and TDS; however, the lines intersect and correlation coefficients for the swept basin are low. The regression line for lead for the swept basin was not plotted due to the limited range of lead concentrations and the resulting low correlation.

The total washoff loads for the same four constituents are of no benefit in clarifying the results. These are shown in figures 6.27 through 6.30. Although the John North swept line appears above the unswept line in all four cases, low correlations or points clustered in a narrow range result in questionable significance.

An investigation of the ratios of swept to unswept basins was completed and is presented in table 6.9 for EMC and 6.10 for total washoff. Once again the unswept to unswept ratio was calculated and used to normalize the swept to unswept ratios. Results for John South swept are included even though only 3 data points are involved.

Table 6.9 shows a significant reduction in EMC for John South swept with 9 of the 10 constituents showing reductions and an overall normalized swept to unswept ratio of 0.84 with a standard deviation of 0.10. Unfortunately, these results are based on just 3 events. There is virtually no change indicated for the John North swept condition. Although 6 of the 10 constituents show small reductions, the overall normalized ratio is 1.00 with a standard deviation of .16.

The ratios of total washoff loads in table 6.10 paint an even more convincing picture of sweeping effectiveness for John South. All 10 constituents show reductions with an overall normalized ratio of .60 and a low standard deviation of .11. Unfortunately, these results again are based on only 3 points. The John North swept data for 4 to 14 events

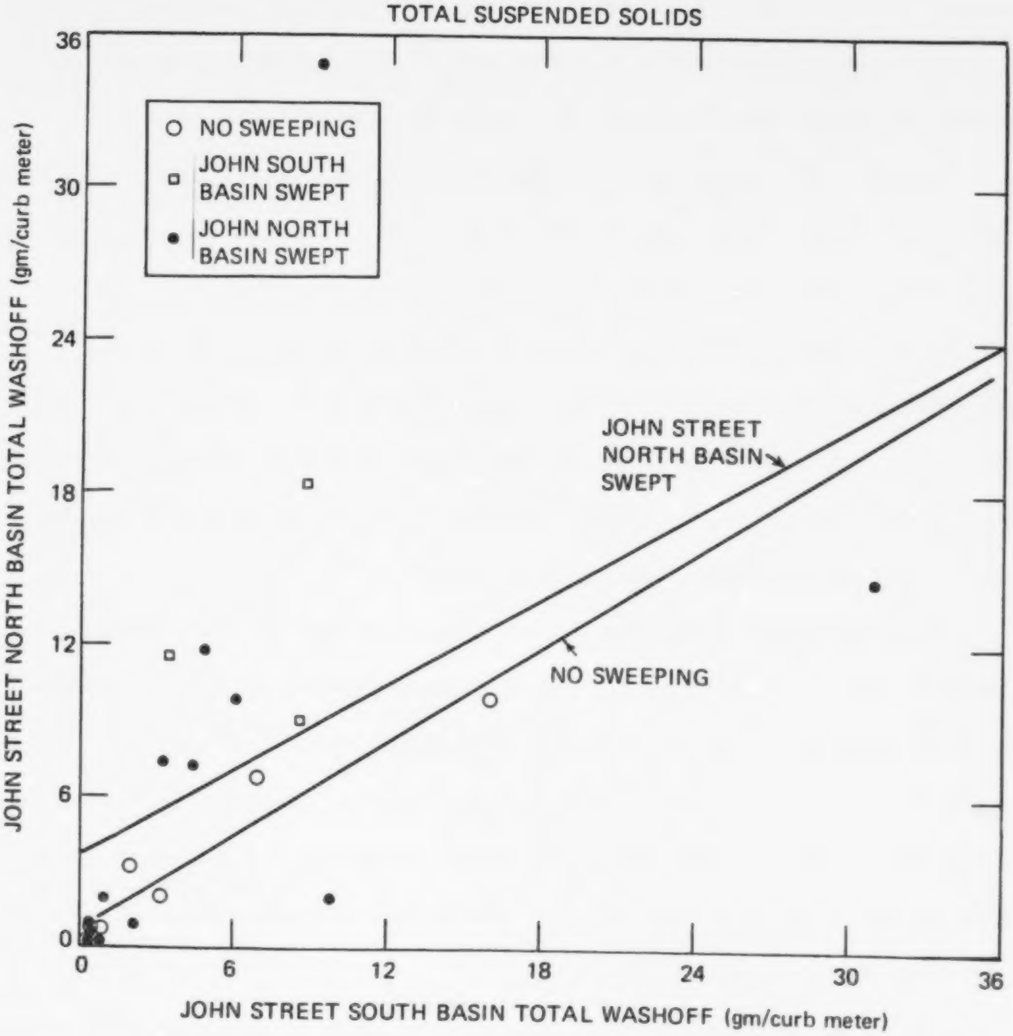

Figure 6.27 Total washoff loads of TSS for John basins

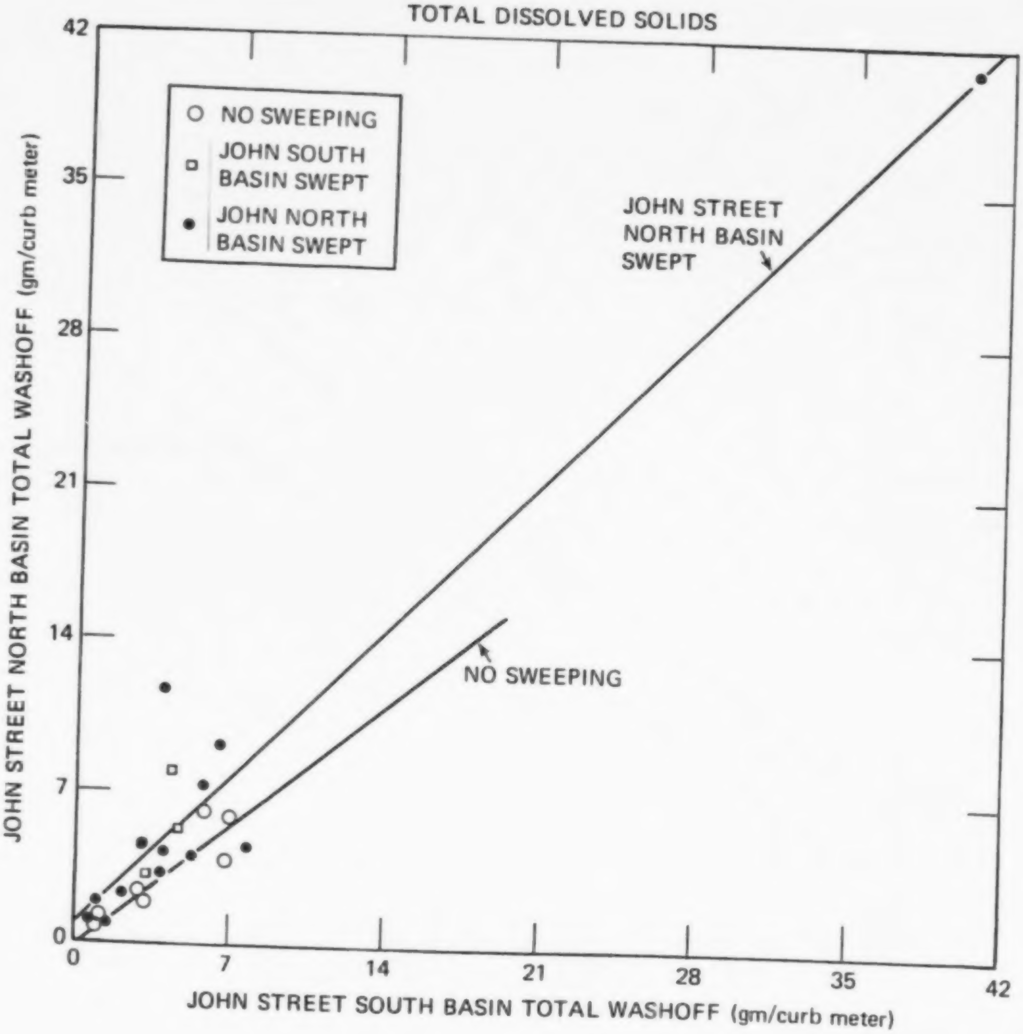

Figure 6.28 Total washoff loads of TDS for John basins

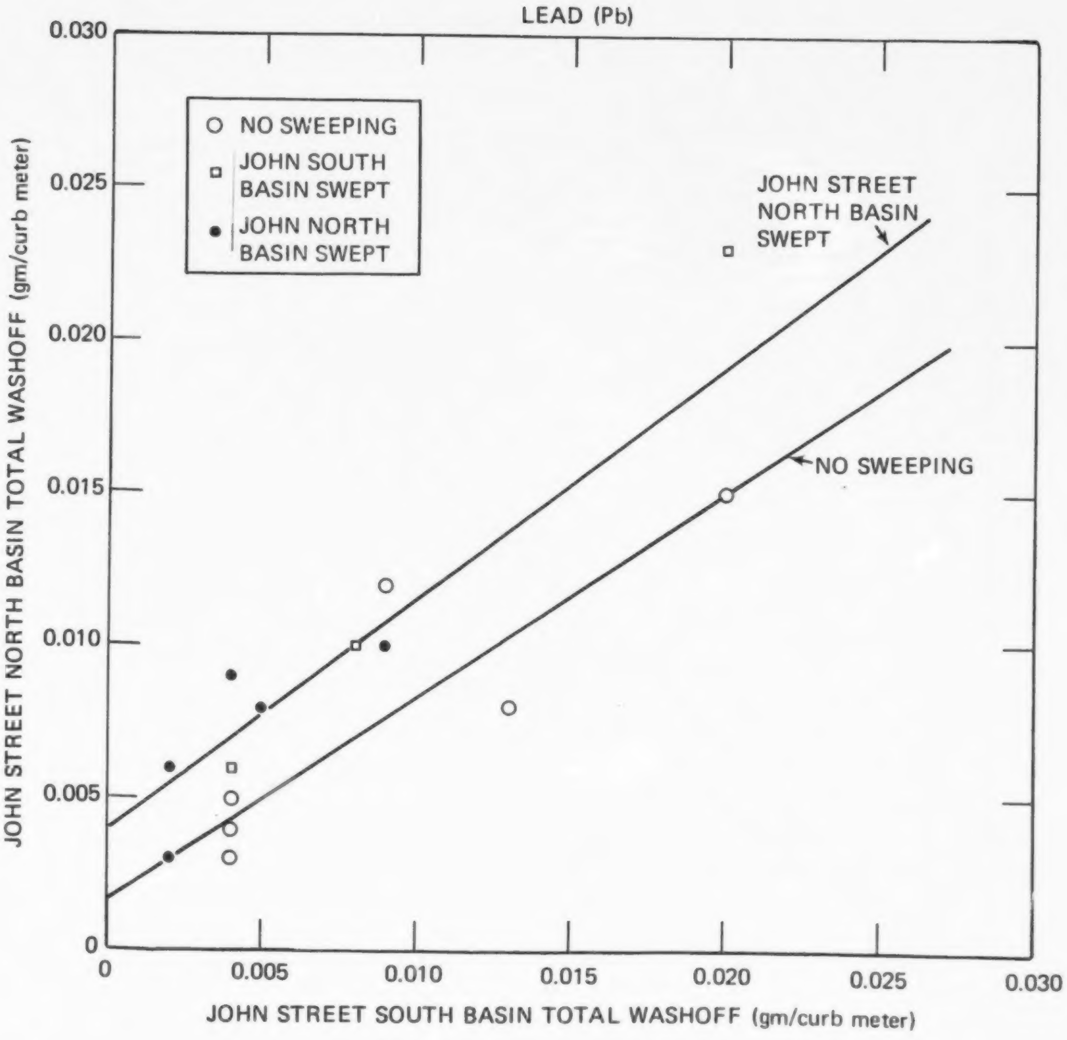

Figure 6.29 Total washoff loads of Lead for John basins

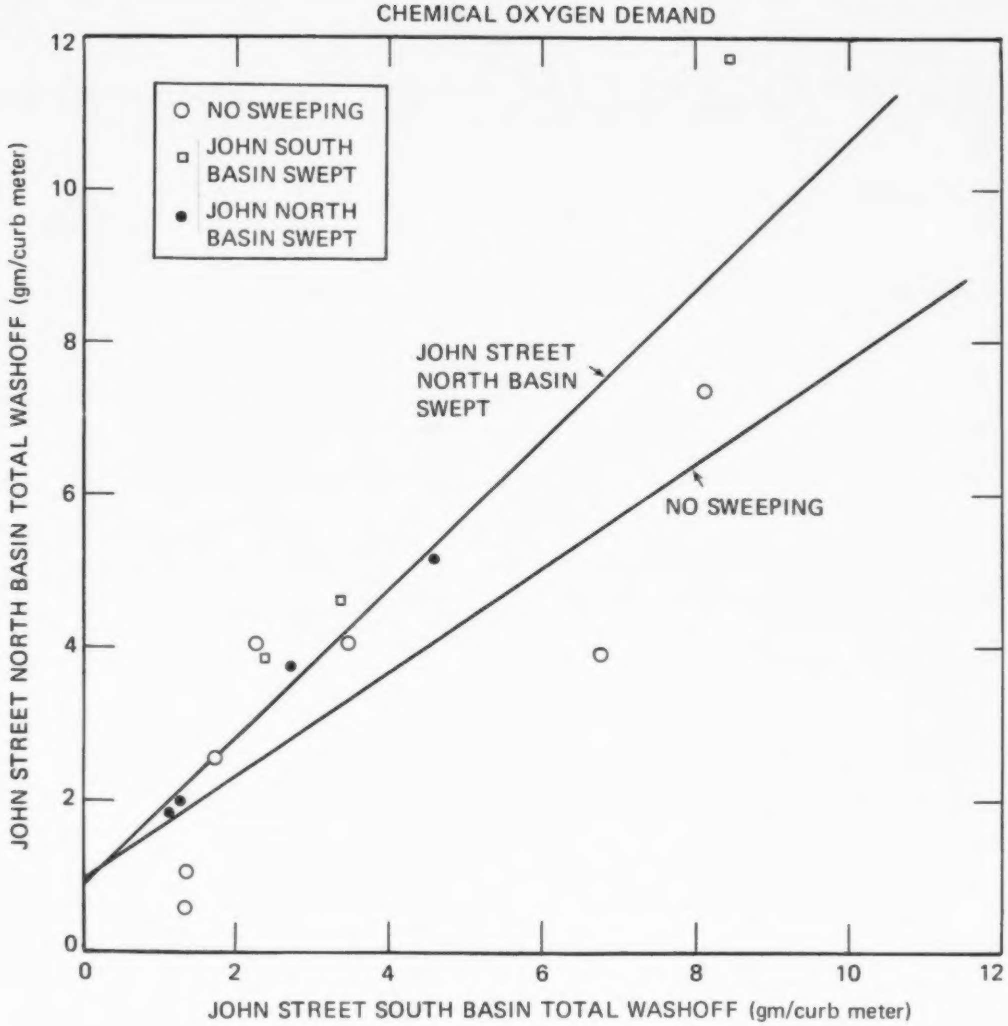

Figure 6.30 Total washoff loads of COD for John basins

Table 6.9 Ratios of Swept to Unswept Event Mean Concentrations for the John Street South and John Street North Basins.

	JS UNSWEPT / JN UNSWEPT			JS SWEPT / JN UNSWEPT				JN UNSWEPT / JS UNSWEPT			JN SWEPT / JS UNSWEPT			
	#	MEAN	S.D.	#	ACTUAL MEAN	S.D.	NORMAL MEAN	#	MEAN	S.D.	#	ACTUAL MEAN	S.D.	NORMAL MEAN
TSS	7	.74	.25	3	.56	.27	.76	7	1.50	.54	15	1.53	.89	1.02
TDS	7	.98	.19	4	.75	.08	.77	7	1.05	.20	15	.99	.19	.94
Lead	7	.86	.22	3	.78	.38	.91	7	1.03	.28	6	1.59	.62	1.54
Copper	7	.63	.61	3	.58	.27	.92	7	2.72	1.59	6	2.42	2.22	.89
Iron	7	.88	.33	3	.66	.36	.75	7	1.29	.52	7	1.34	.536	1.04
COD	7	.94	.28	3	.78	.28	.83	7	1.25	.36	5	1.30	.12	1.04
Nitrate-Nitrite N	7	1.16	.37	3	1.23	.25	1.06	7	.93	.24	7	.91	.36	.98
Phosphorus	7	.95	.32	3	.86	.11	.91	7	1.18	.47	7	1.09	.44	.92
Sulfate	7	.98	.11	3	.79	.24	.81	7	1.03	.13	15	.94	.16	.91
Chloride	7	1.01	.32	3	.78	.18	.77	7	1.08	.34	16	.99	.51	.92
G. MEAN		.90			.76		.84		1.24			1.24		1.00
S.D.		.16			.17		.10		.39			.39		.16

Table 6.10 Ratios of Swept to Unswept Total Washoff Loads for the John Street South and John Street North Basins.

	JS UNSWEPT / JN UNSWEPT			JS SWEPT / JN UNSWEPT				JN UNSWEPT / JS UNSWEPT			JN SWEPT / JS UNSWEPT			
	#	MEAN	S.D.	#	ACTUAL MEAN	S.D.	NORMAL MEAN	#	MEAN	S.D.	#	ACTUAL MEAN	S.D.	NORMAL MEAN
TSS	7	1.02	.38	3	.57	.33	.56	7	1.10	.41	14	1.94	1.48	1.76
TDS	7	1.36	.31	3	.80	.22	.59	7	.77	.17	14	1.28	.67	1.66
Lead	7	1.16	.32	3	.78	.10	.67	7	.92	.28	5	1.89	.74	2.05
Copper	5	.73	.36	3	.56	.10	.77	5	1.80	1.09	5	1.82	.72	1.01
Iron	7	1.18	.54	3	.58	.24	.49	7	1.03	.52	7	1.58	.68	1.53
COD	7	1.20	.61	3	.68	.06	.57	7	1.03	.50	4	1.45	.25	1.41
Nitrate-Nitrite N	7	1.48	.33	3	1.12	.59	.76	7	.70	.14	6	1.12	.52	1.59
Phosphorus	7	1.25	.47	3	.77	.14	.62	7	.98	.62	6	1.29	.70	1.31
Sulfate	7	1.38	.35	3	.81	.20	.59	7	.77	.21	14	1.24	.47	1.61
Chloride	7	1.42	.51	3	.60	.19	.42	7	.80	.35	14	1.21	.80	1.00
G. MEAN		1.20			.71		.60		.95			1.45		1.46
S.D.		.25			.16		.11		.26			.29		.34

indicates a fairly consistent increase in washoff loads when that basin is swept. Nine of 10 constituents show an increase with an overall mean normalized ratio of 1.46 and standard deviation of .34.

Series Analysis

The series analysis simply compares the results of a basin's performance during a control period (no sweeping) with those of its performance during an experimental period (swept). As in the case of the parallel analysis, this study was designed so that each of the four basins would have a control and an experimental data set. Although the series approach is more subject to seasonal and weather related effects than the parallel method, more data points are usually available for analysis.

The log-normal distribution was selected as the mechanism to compare swept and unswept data sets with each basin. The NURP headquarters consultants used this procedure successfully in an interim report[13] and urged the projects to utilize it also. In general, high correlations were obtained using the log-normal distribution on data for this project. The use of this procedure on relatively short term data sets can be misleading. Since the swept and unswept data sets comprise less than one year each, they may display seasonal trends and are not necessarily representative of a long term log-normal distribution.

Mattis Avenue Basins--

Figures 6.31 A and B illustrate that there is only a minor bias in runoff volumes during the swept and unswept periods at either Mattis North or Mattis South. This could have been an important consideration with this type of analysis, but need not be considered here.

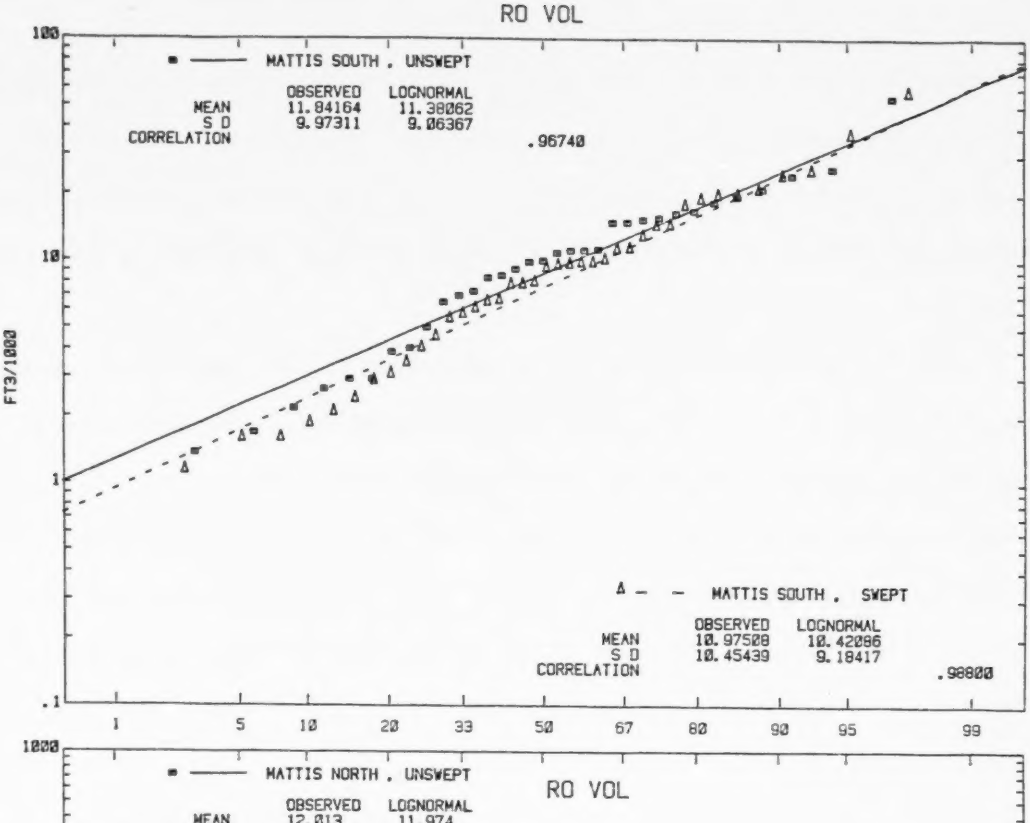

Figure 6.31 Distribution of runoff volumes for Mattis basins

For consistency with the earlier parallel analysis, plots of TSS, TDS, lead, and COD will be presented and the other constituents summarized. Figures 6.32 and 6.33 show EMC values for these data sets and lines of best fit for the Mattis South basins on log-normal coordinates. Also presented are the observed and log-normal mean and the standard deviation for the swept and unswept events as well as the correlation coefficient for each line.

Table 6.11 summarizes log-normal analyses for 10 constituents using both EMCs and loads. The ratios are calculated using the line values read at the 50 percent probability level in all cases. The results are somewhat erratic as shown in table 6.11. Using EMC values, Mattis South data show beneficial effects of sweeping for only 5 of 10 constituents, but the overall mean is .82. The load values for Mattis South are more consistent, with 8 of 10 showing beneficial effects and a mean of .78. The standard deviations of about 40 percent of the mean for Mattis South indicate the inconsistency in these ratios. The EMCs for Mattis North strongly indicate a beneficial effect from sweeping, but the loads show just the opposite.

Figures 6.34 and 6.35 present EMC values for the Mattis North basin. The EMC values and the total loads for Mattis North are presented in table 6.9. The EMC values indicate that 8 of 10 constituents are reduced due to sweeping with a mean of 0.83. Loads are reduced for only 2 of the 10 constituents with an overall ratio of 1.18. The significance of these and other results will be discussed later in this section.

John Street Basins--

One of the advantages of the series analysis is evident in the fact that there are 15 points in the John South swept data set as opposed to 3

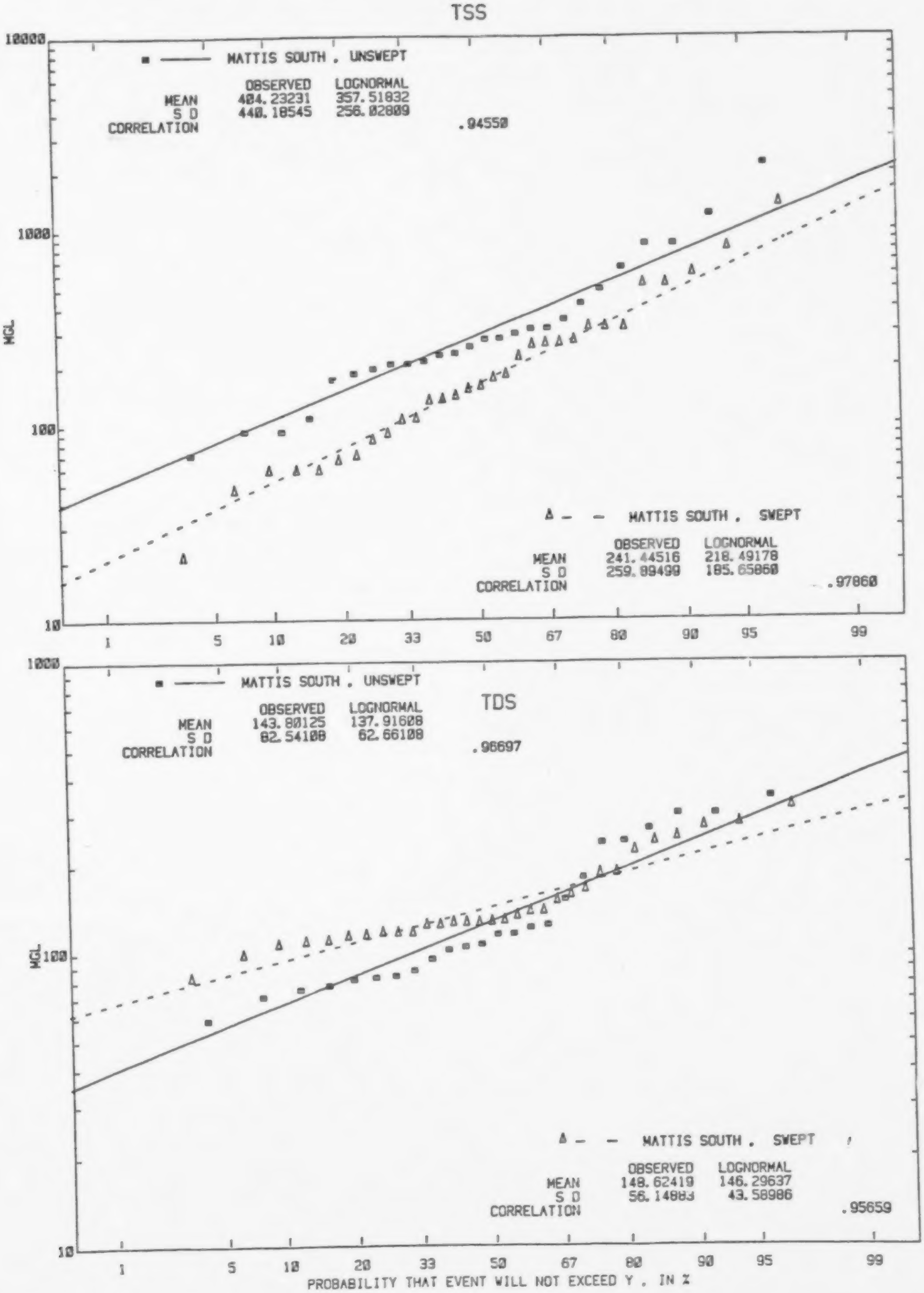

Figure 6.32 Distribution of EMC values for TSS and TDS - Mattis South basin

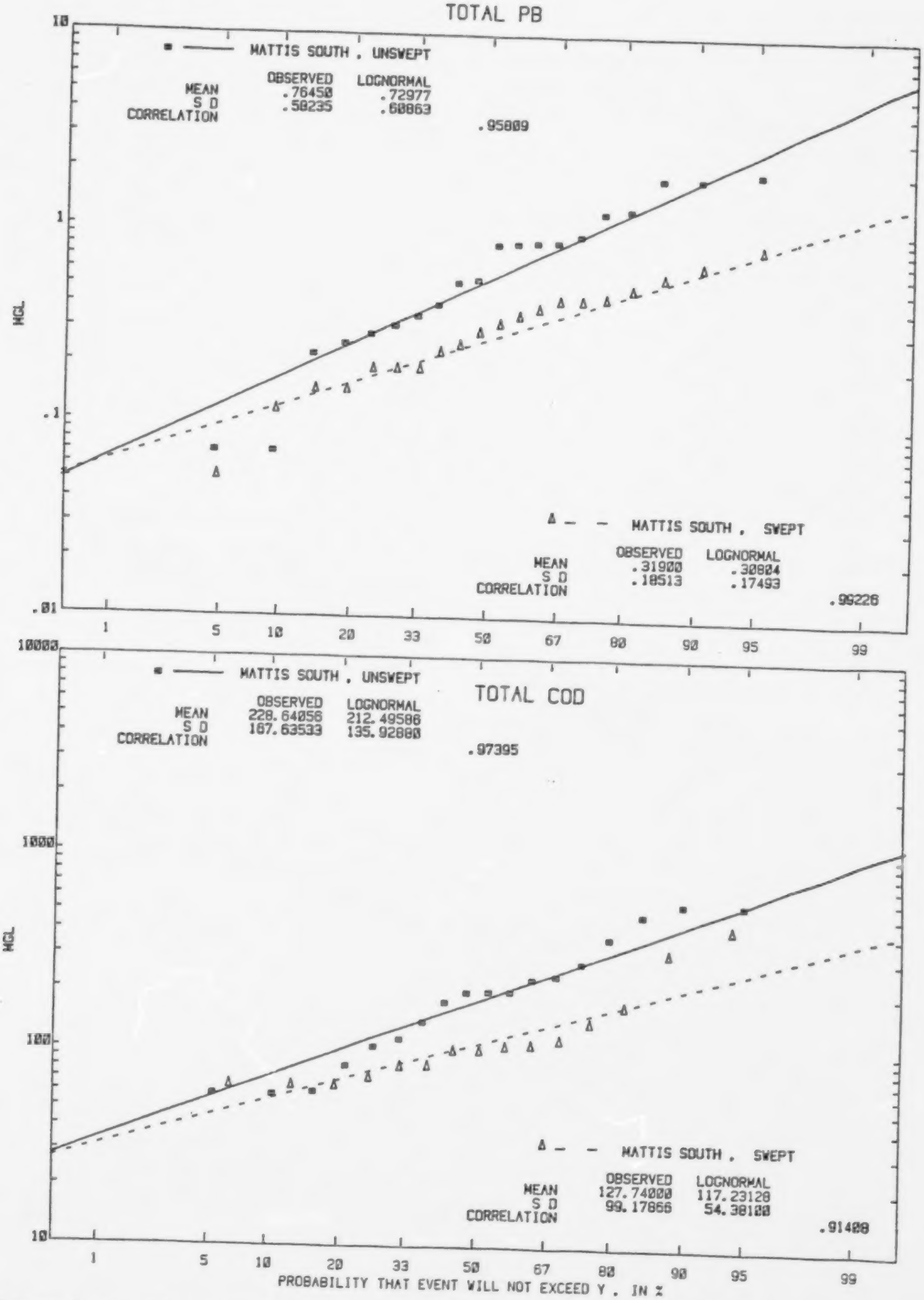

Figure 6.33 Distribution of EMC values for Lead and COD - Mattis South basin

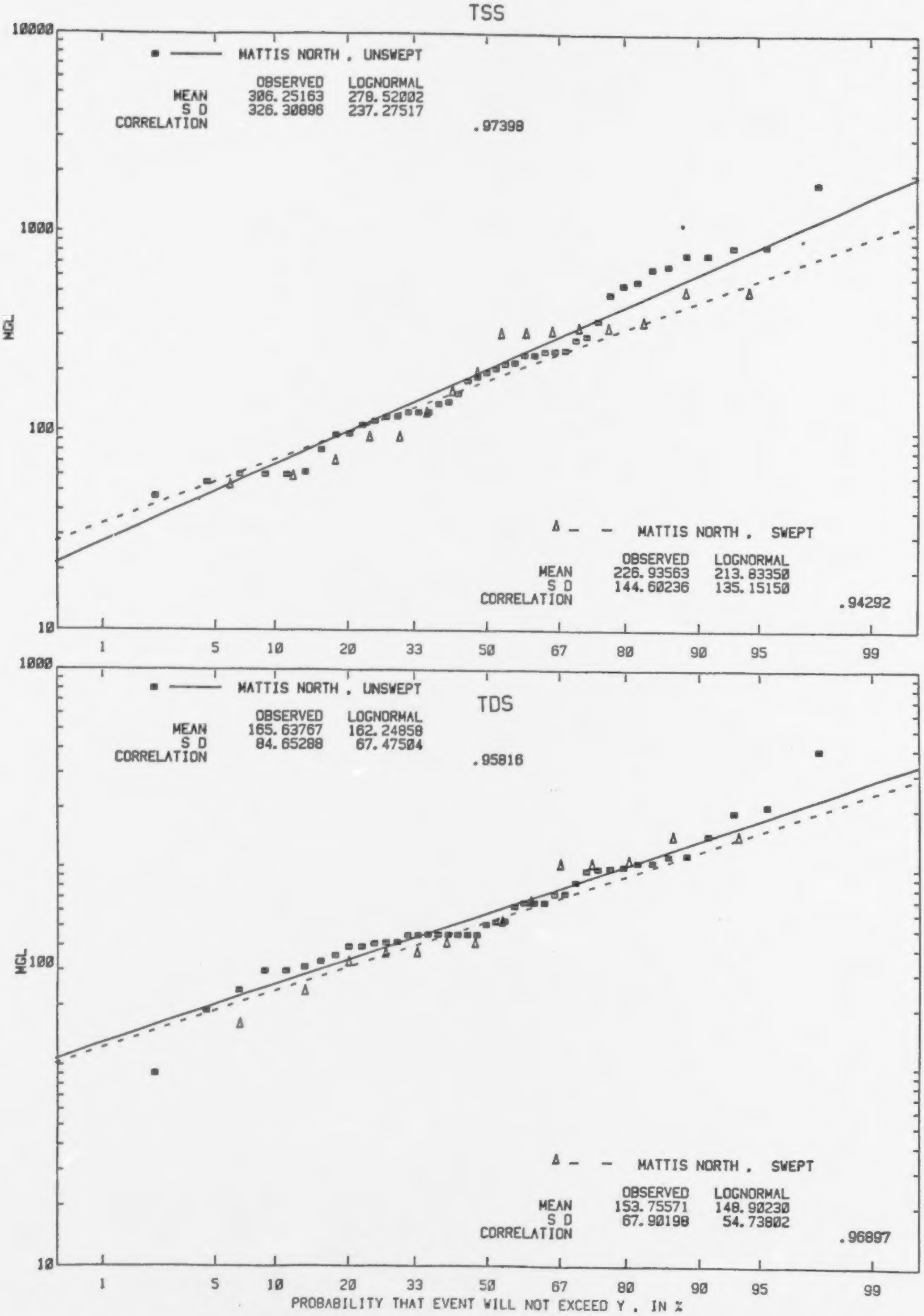

Figure 6.34 Distribution of EMC values for TSS and TDS - Mattis North basin

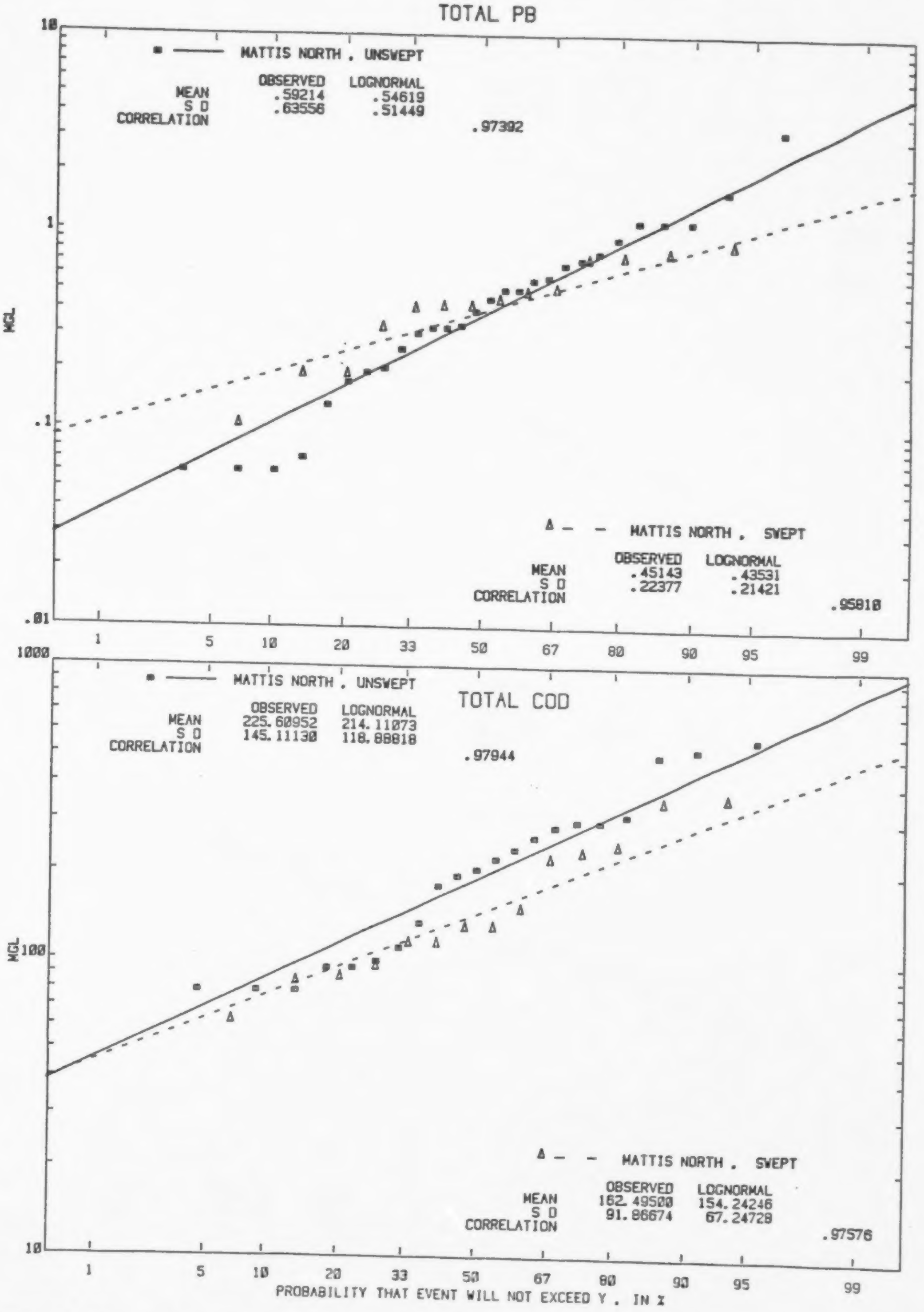

Figure 6.35 Distribution of EMC values for Lead and COD - Mattis North basin

Table 6.11. Ratios of Swept to Unswept EMCs and Loads Using Median Log-Normal Values for Mattis Avenue Basins

	MATTIS SOUTH BASIN		MATTIS NORTH BASIN	
	EMC	LOAD	EMC	LOAD
TSS	.56	.51	.87	1.05
TDS	1.12	.91	.94	1.14
Lead	.50	.47	1.01	1.39
Copper	1.24	1.09	.61	.85
Iron	.52	.50	.93	1.35
COD	.60	.67	.76	1.00
Nitrate-Nitrite N	1.34	1.62	.75	.96
Phosphorus	.76	.76	.82	1.03
Sulfate	1.17	.94	1.15	1.65
Chloride	1.03	.88	.64	.72
G. MEAN	.82	.78	.83	1.18
S.D.	.33	.31	.17	.27

Table 6.12. Ratios of Swept to Unswept EMCs and Loads Using Median Log-Normal Values for John North Basin

	EMC	LOAD
TSS	.56	.62
TDS	1.06	1.17
Lead	.72	.49
Copper	1.90	1.24
Iron	.38	.30
COD	.58	.63
Nitrate-Nitrite N	1.09	.88
Phosphorus	.87	.70
Sulfate	1.01	1.16
Chloride	.85	.85
G. MEAN	.82	.74
S.D.	.37	.34

in the parallel analysis. Figures 6.36 A and B compare the distribution of runoff in swept and unswept events for the John Street basins. The obvious skew between the swept and unswept periods for John South cannot be ignored. It has certainly biased the EMC and total washoff values and cannot be adjusted or normalized. The log-normal analysis will not be performed for the John South swept data set.

Figures 6.37 and 6.38 show the log-normal distribution of EMC values for John North basin. The log-normal distributions show distinct EMC reduction for TSS and COD, though the points seem to merge at higher concentrations. Table 6.12 shows that ratios of swept to unswept periods are less than 1 for 6 of the 10 constituents and exhibit a mean ratio of .82.

Figures 6.39 and 6.40 show that loads follow the same general pattern as EMC values for John North. Table 6.12 shows that 7 of the 10 constituents display swept to unswept ratios less than 1.0 and have an overall ratio of .74.

Summary of Water Quality Results

Table 6.13 summarizes the swept to unswept ratios for both the John Street basins and the Mattis Avenue basins and for both EMC values and total washoff loads. The series or log-normal results for John South swept have been deleted due to the bias in runoff during the swept and unswept periods. The parallel analysis of the John South swept data has been retained, even though it consists of only 3 events. In table 6.13 the basin shown at the head of the column is the swept basin. Under the paired events column the swept basin is compared with its control basin for the same events. Under the log-normal column the swept basin is compared with itself during an unswept period. Geometric means and

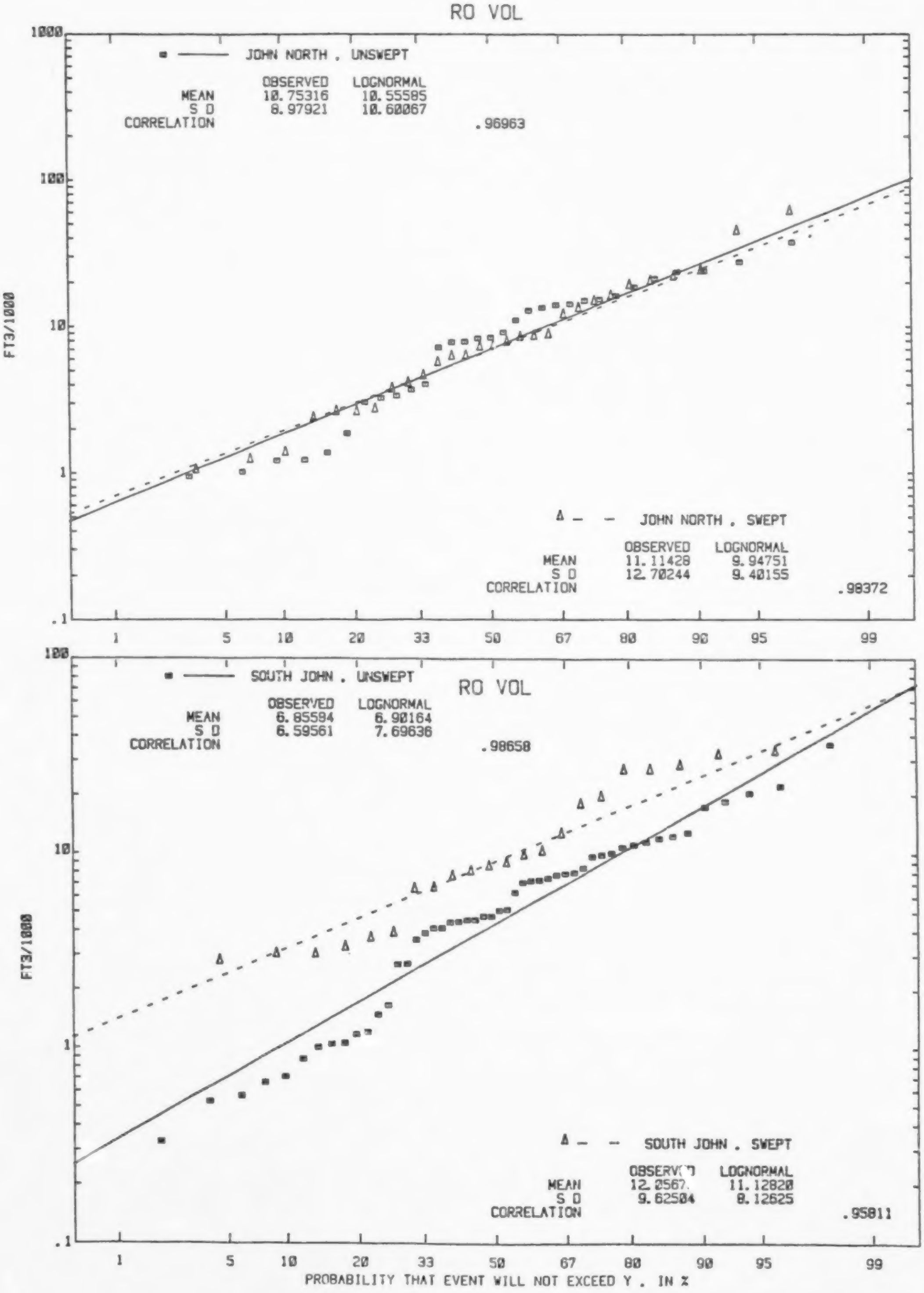

Figure 6.36 Distribution of runoff volumes for John basins

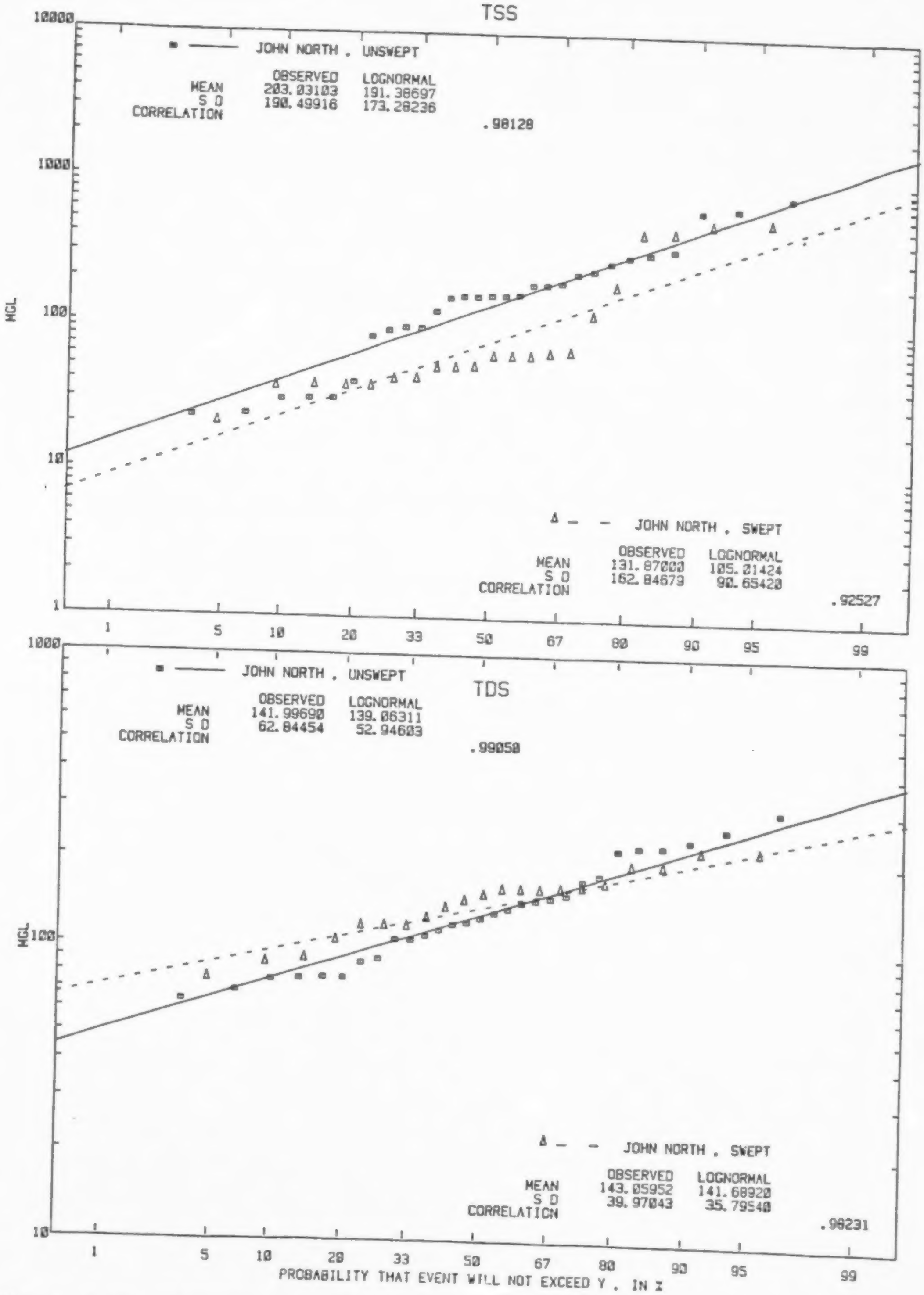

Figure 6.37 Distribution of EMC values for TSS and TDS - John North basin

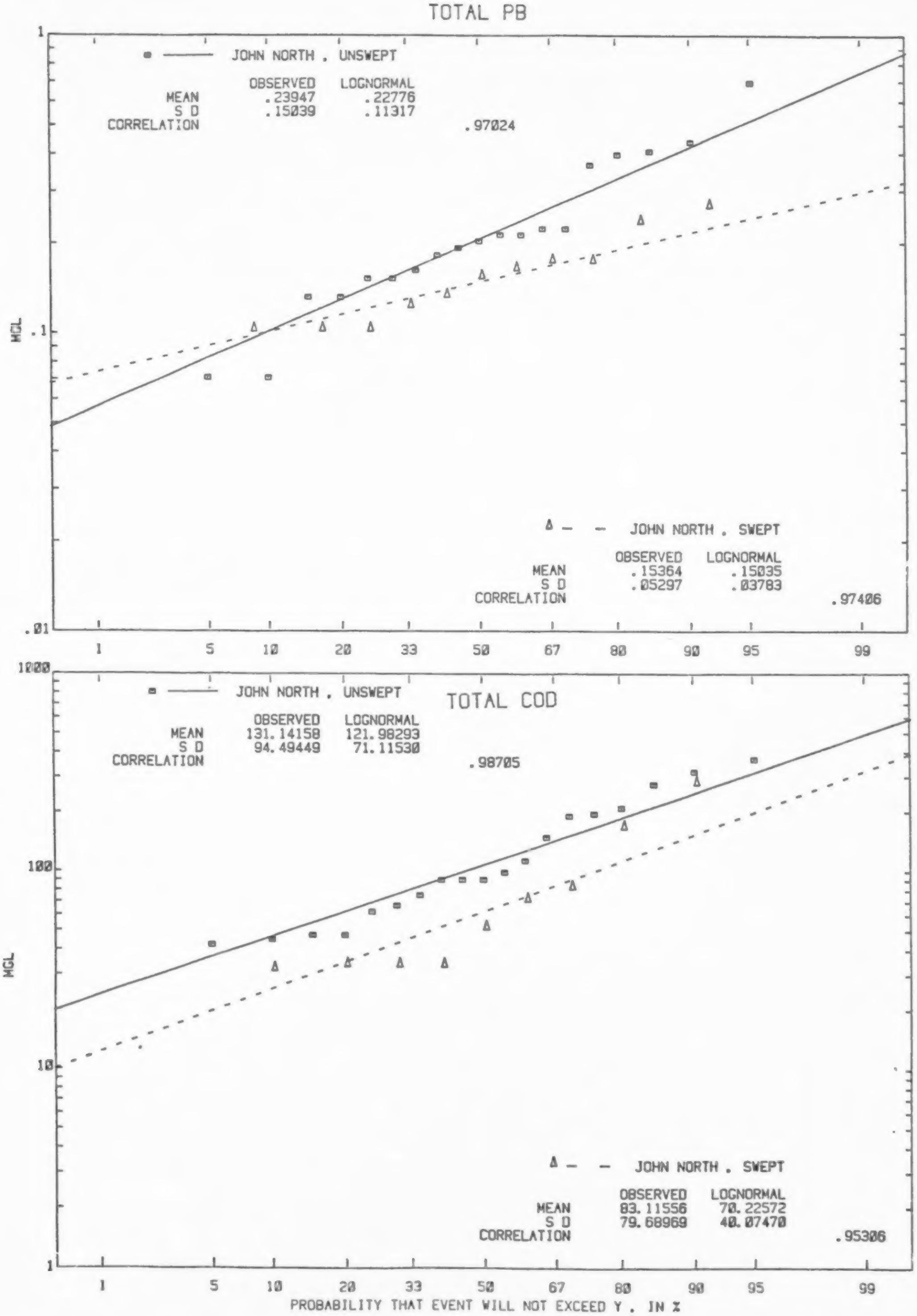

Figure 6.38 Distribution of EMC values for Lead and COD - John North basin

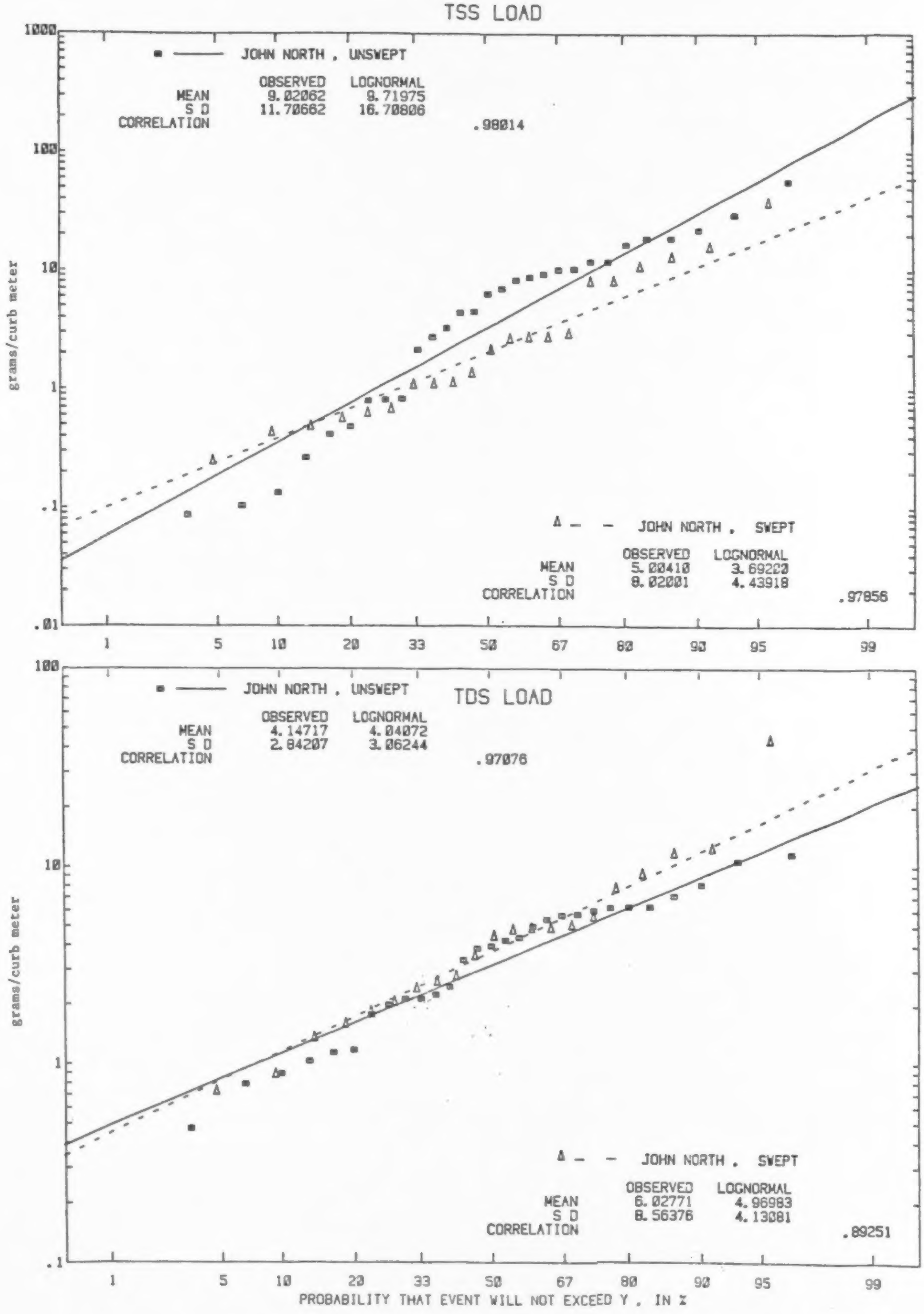

Figure 6.39 Distribution of total washoff loads of TSS and TDS John North basin

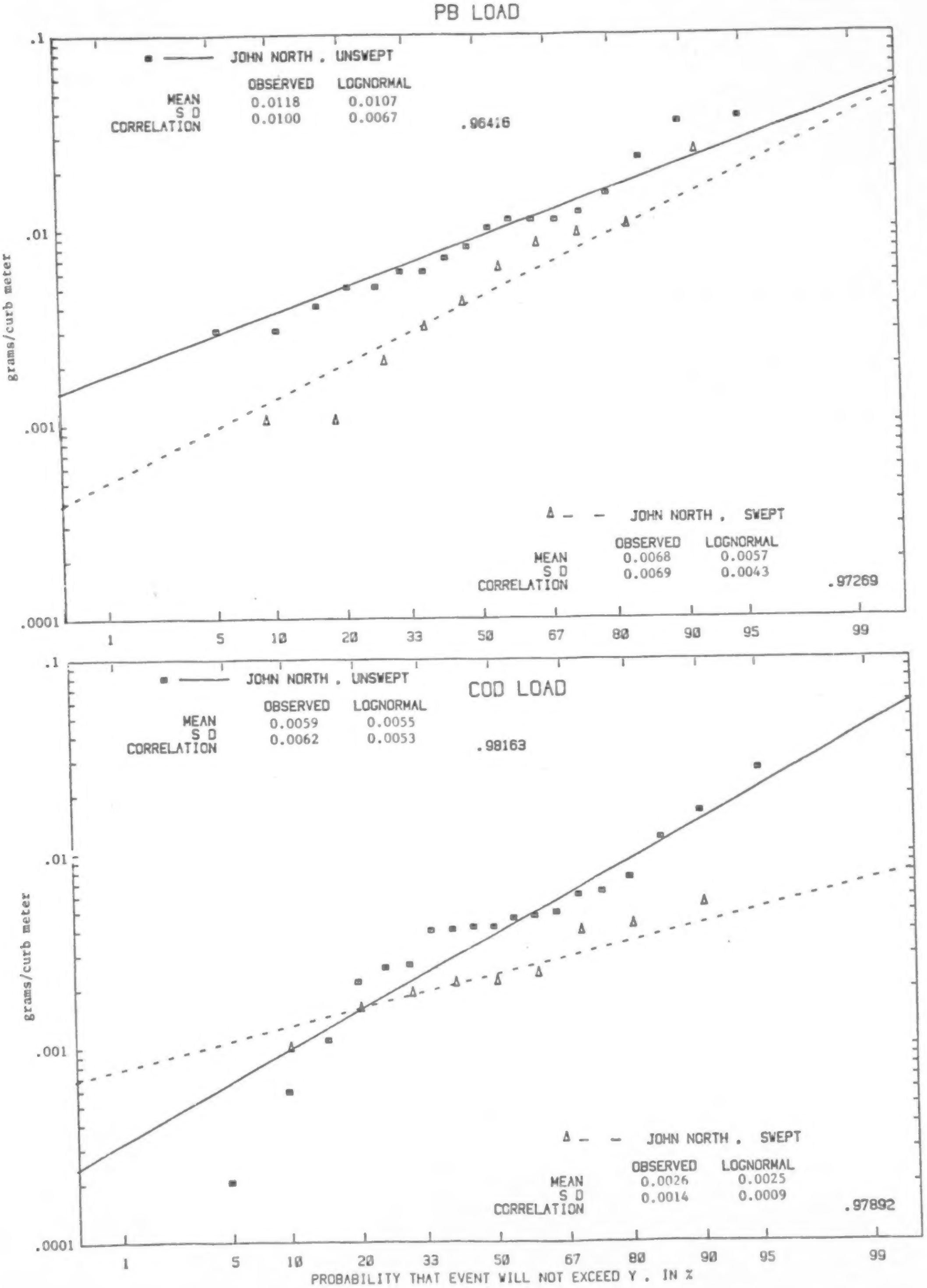

Figure 6.40 Distribution of total washoff loads of Lead and COD John North basin

Table 6.13 Ratios for Swept vs. Unswept Conditions Using Mean Values of EMCs or Total Washoff Loads

	JOHN SOUTH				JOHN NORTH				MATTIS SOUTH				MATTIS NORTH				EMC		LOAD	
	PAIRED EVENTS		LOG NORMAL		PAIRED EVENTS		LOG NORMAL		PAIRED EVENTS		LOG NORMAL		PAIRED EVENTS		LOG NORMAL					
CONSTITUENT	EMC	LOAD	EMC	LOAD	EMC	LOAD	EMC	LOAD	EMC	LOAD	EMC	LOAD	EMC	LOAD	EMC	LOAD	G. MEAN	S.D.	G. MEAN	S.D.
TSS	.76	.56			1.02	1.76	.56	.62	1.23	1.07	.56	.51	1.00	1.57	.87	1.05	.83	.25	.92	.48
TDS	.77	.59			.94	1.66	1.06	1.17	.94	.70	1.12	.91	.95	2.03	.94	1.14	.95	.11	1.12	.45
LEAD	.91	.67			1.54	2.05	.72	.49	.89	1.31	.50	.47	1.71	2.09	1.01	1.39	.96	.42	1.03	.71
CU	.92	.77			.89	1.01	1.90	1.24	1.49	.59	1.24	1.09	1.06	2.90	.61	.85	1.10	.42	1.06	.56
FE	.75	.49			1.04	1.53	.38	.30	1.02	.75	.52	.50	1.55	2.54	.93	1.35	.81	.40	.84	.70
COD	.83	.57			1.04	1.41	.58	.63	.78	.83	.60	.67	1.36	1.54	.76	1.00	.82	.25	.89	.36
NO_2-NO_3	1.06	.76			.98	1.59	1.09	.88	1.25	.84	1.34	1.62	1.15	2.07	.75	.96	1.07	.20	1.16	.47
P	.91	.62			.92	1.31	.87	.70	.88	1.04	.76	.76	1.28	.72	.82	1.03	.91	.15	.85	.23
SO_4	.81	.59			.91	1.61	1.01	1.16	.91	.79	1.17	.94	1.33	1.85	1.15	1.65	1.01	.20	1.14	.50
CL_2	.77	.42			.92	1.00	.85	.85	.66	.65	1.03	.88	1.74	2.65	.64	.72	.89	.31	.87	.52
G. MEAN	.84	.60			1.00	1.46	.82	.74	.97	.83	.82	.78	1.29	1.88	.83	1.08				
S.D.	.10	.11			.16	.34	.37	.34	.24	.21	.33	.31	.28	.76	.17	.27				

standard deviations are presented for each basin by type of analysis and for each constituent by EMC and load. The standard deviation presented is the average of the difference between the mean plus one standard deviation and the mean minus one standard deviation.

Looking at the basins individually, John South shows a benefit from sweeping for three events). John North shows a benefit in the log-normal analysis but degradation in the paired basin analysis. Mattis South shows some benefit for all analyses and Mattis North only shows benefit in the log-normal EMC analysis. Based on the individual constituents, 7 of 10 show benefit from sweeping in the EMC analysis but only 5 of 10 for the load analysis.

In order to better quantify the results, Hypothesis Testing was used to examine the sets of ratios. Logs of the ratios were used to increase the likelihood of a normal distribution. The test statistic used was

$$T = \frac{(\overline{x} - \mu_o)\sqrt{n}}{s}$$

where: T = the test statistic
$\overline{x}$ = mean of athe logs of the ratios
μ_o = mean of the assumed population
n = number of values
s = standard deviation
and μ = true mean of population

The following hypotheses were tested at the 90 percent confidence level:

1. The true mean of the population is less than 1.00
2. The true mean of the population is less than .90
3. The true mean of the population is greater than 1.00
4. The true mean of the population is greater than 1.10

Results of the tests at the 90 percent confidence level by basin were as follows:

	True Mean <1.00	True Mean >1.00	Neither
John South	2	0	0
John North	1	1	2
Mattis South	3	0	1
Mattis North	1	3	0

	True Mean <0.90	True Mean >1.10	Neither
John South	2	0	0
John North	0	1	3
Mattis South	0	0	4
Mattis North	0	2	2

Again the results are conflicting. There are 7 data sets below 1, 4 sets above 1, and 3 indeterminant, indicating a slight edge toward sweeping effectiveness. When the test is made more stringent by testing against ratios of .9 and 1.1 (this would amount to a 10 percent decrease or increase in EMC or load), the results change. Under the more stringent test there are 2 data sets below 0.9, 3 above 1.1 and 9 in between. This indicates that there is a 90 percent chance that 2 out of the 14 data sets tested showed EMC or load reduced by 10 percent or more; 3 of the 14 data sets showed EMC or load increased by 10 percent or more; and 9 of the 14 data sets showed changes of less than 10 percent.

A similar analysis of the data by constituent indicates that at the 90 percent confidence level the true mean EMC ratios of TSS, COD and P are less than 1.0 and none are less than 0.9. It further shows that P is the only constituent with a true mean load ratio less than 1.0 and that none are less than 0.9. None of the constituents show EMC or load ratios with true means greater than 1.0 at the 90 percent confidence level.

Particle Size Distribution of Runoff Solids

In 1981, runoff samples from all basins were analyzed for size distribution of suspended solids. Sample volumes of 10-20 liters were needed to provide enough solids for analysis, so only flow-weighted composite samples or manually collected discrete samples were used in these determinations. Composite samples from three to five events at each site were split so that routine constituent analyses could be run for one portion and particle size distribution of solids for the other. During one event at one site, five discrete samples were collected at varying intervals and analyzed in the same fashion as the composite samples.

The first step in handling a sample was to split off the volume needed for constituent analysis. After the remainder of the sample had been allowed to settle at least 48 hours, the supernatant was drawn off and the concentrated solids were washed on a 63μ screen. The material remaining on the screen was dried, weighed, and sieved into the size groups used for the street dirt samples. The material passing the screen was collected with the rinse water and was again allowed to settle. After the supernatant was removed the fines were dried and weighed. The weights of each coarse fraction and the fines were divided by the sum of all fractions to determine the percentages of the solids load corresponding to the different size ranges. These percentages for each sample and some pertinent data from the events at the sites are given in table 6.14.

The solids distributions in the composite samples, except for those from one event, were generally similar, with 80-100 percent of the solids smaller than 250μ. Since these samples represented several events with a variety of rainfall amounts and intensities, the predominance of fines in the makeup of the solids load appears to be characteristic of storm runoff from these basins. An exception from this observed condition occurred during the event of April 10. The solids in the samples from all four sites for this event were well distributed across the size range tested.

Table 6.14 Particle Size Distribution of Runoff Solids in Selected Samples

Composite Samples

Site	Date	Rain (in.)	Peak Flow (cfs)	Runoff Volume (ft^3)	TSS Conc. (mg/l)	Particle Size Distribution (percent finer than size) 2000μ	1000μ	500μ	250μ	125μ	63μ
Mattis North											
	4/10	.54	4.9	22650	197	78	69	62	47	26	5
	6/8	.10	1.7	7000	480	100	100	100	100	84	33
	6/15	.78	5.0	17004	302	100	100	99	94	86	80
	6/24	.31	3.7	10200	124	100	100	99	93	85	80
	7/4	1.85	8.0	68616	100	100	100	100	100	100	99
Mattis South											
	4/10	.52	9.1	24516	256	97	87	71	40	16	3
	5/10	.53	6.1	19020	134	100	100	100	100	86	52
	6/15	.78	9.7	53328	230	98	94	89	80	72	66
John South											
	4/10	.54	6.3	16890	292	96	89	76	53	27	4
	5/10	.61	4.7	19812	82	100	100	100	84	60	28
	6/24	.34	5.0	7998	202	100	100	98	89	78	68
	7/4	1.71	6.1	49518	384	100	100	100	99	95	88
John North											
	4/10	.54	2.8	18186	158	88	79	61	35	17	3
	6/15	.91	11.7	37200	306	97	94	91	82	73	64
	7/4	1.71	11.7	81546	138	100	100	100	99	95	90

Manual Discrete Samples

Site	Date	Time	Rain Acc. (in.)	Flow (cfs)	TSS Conc. (mg/l)	Particle Size Distribution (percent finer than size) 2000μ	1000μ	500μ	250μ	125μ	63μ
Mattis South											
	6/12	0842	0.01	0.0	-						
		0916	0.17	0.4	168	100	100	100	100	100	98
		0919	0.22	4.0	611	100	100	100	100	98	94
		0920	0.22	4.7	633	-	-	-	-	-	-
		0923	0.25	4.0	546	100	100	100	100	99	98
		0933	0.26	1.4	316	100	100	99	99	97	95
		0938	0.27	0.8	178	100	100	100	100	99	98
		1102	0.34	0.1	-	-	-	-	-	-	-

Since neither the volume nor the intesity of the rainfall in the storm was extraordinary, the only aspect in which this event differed from the others was the time of year it occurred. This suggests a seasonal effect on either the composition of the load at the source or the transport of the load to the inlets and through the sewers. Inspection of the street dirt records for the basins shows no substantial difference in size distribution of loads between April and later months except that which is due to the effects of street sweeping, so the latter suggestion seems more likely. Another possibility is that the coarser materials in the samples did not originate on the street surface at the time of the event, but rather from deposits in the manholes and sewers which had accumulated during the winter and early spring. The runoff of April 10 could have scoured such deposits from the system and carried them out of the basins. If the deposits of coarse material were not replenished during subsequent small events, and only fines were washed from the street surfaces, then scour might not have supplied any more coarse solids, and fines could have predominated in runoff loads for later events.

At the Mattis South site on June 12, a storm began at 0842 and ended at 1102, with a total rainfall of 0.34 inch. During the first hour of the storm, several discrete samples were collected manually, and five of these, collected between 0916 and 0938, were analyzed for size distribution of runoff solids. The data from these analyses are also listed in table 6.14. During the period of sampling the flow rose from 0.4 to 4.7 cfs, then receded to 0.8 cfs. Total suspended solids concentrations in the samples tested for size distribution ranged from 168-611 mg/l, while the peak concentration observed in any sample was 663 mg/l. The samples were well distributed through the rising limb, peak, and falling limb of the runoff hydrograph.

The predominance of fines in the samples analyzed for size distribution of solids is clear. In all five cases, 94-98 percent of the solids were smaller than 63μ. While the storm could not have been called a major event, it was representative of common summer storms. This suggests that most of the solids load in runoff is made up of fines, at least in summer. If this is true, then control of coarse material through street sweeping may have very little effect on runoff loads.

ATMOSPHERIC DEPOSITION SAMPLING

Throughout the runoff sampling seasons, atmospheric fallout samples were collected at three sites in or near the study basins. Separate wet and dry fallout samples were collected from the start of the project; bulk fallout sampling was added in May 1980. Samples were collected with the intent of identifying any significant contribution from the atmosphere to the street load during dry periods and to runoff quality during storms. Samples kept for analysis were associated with specific events, and results included in consideration of event washoff loads.

Tables 6.15-6.18 are summaries of results of all deposition sampling. From 21 to 26 wet fallout samples were kept from each site. Table 6.15 contains the minimum, maximum, and mean of concentration values reported above detection limits for ten constituents. A comparison of event mean concentrations of six of these constituents in runoff to the corresponding wet fallout concentrations was performed on a site-by-site basis for all events where both kinds of data were available. Table 6.16 shows the results of that comparison. It features the minimum, maximum, and mean of

Table 6.15 Wet Deposition Quality Summary

MATTIS NORTH

Constituent	min	max	avg	No. of averaged results	No. of trace results
Ammonia-N	0.10	1.82	0.39	22	0
Nitrate/Nitrite-N	0.24	0.95	0.43	20	0
Phosphorus	0.002	0.05	0.014	17	5
Lead	0.02	0.06	0.04	2	21
Copper	0.003	0.128	0.033	14	9
Iron	0.007	0.12	0.035	21	2
Manganese	0.003	0.012	0.007	6	17
Calcium	0.16	3.4	1.11	5	12
Magnesium	0.17	0.50	0.32	3	14

Total Samples = 23

MATTIS SOUTH

Constituent	min	max	avg	No. of averaged results	No. of trace results
Ammonia-N	0.10	1.63	0.45	21	0
Nitrate/Nitrite-N	0.16	0.86	0.46	19	1
Phosphorus	0.002	0.07	0.024	15	6
Lead	0.030	0.035	0.032	2	20
Copper	0.004	0.080	0.029	18	4
Iron	0.006	0.103	0.033	19	3
Manganese	0.003	0.020	0.008	8	14
Calcium	0.005	2.6	0.78	8	9
Magnesium	1.1	3.5	2.3	2	15

Total Samples = 21

JOHN SOUTH

Constituent	min	max	avg	No. of averaged results	No. of trace results
Ammonia-N	0.09	1.65	0.43	25	0
Nitrate/Nitrite-N	0.16	0.84	0.45	22	2
Phosphorus	0.002	0.08	0.022	16	9
Lead	--	0.034	0.034	1	25
Copper	0.004	0.09	0.043	10	16
Iron	0.006	0.12	0.047	21	5
Manganese	0.003	0.016	0.008	10	16
Calcium	0.26	8.0	1.95	7	13
Magnesium	0.17	0.77	0.38	3	17

Total Samples = 26

All constituent values in mg/L

Table 6.16. Comparison of Event Mean Concentrations and Wet Deposition Concentrations of Six Constituents

	MATTIS NORTH		MATTIS SOUTH		JOHN SOUTH		JOHN NORTH	
	EMC	WDC	EMC	WDC	EMC	WDC	EMC	WDC
Ammonia-N								
min	.005	.27	.005	.10	.10	.09	.05	.09
max	.78	1.82	1.12	1.63	1.62	1.65	2.10	1.65
mean	.274	.431	.449	.483	.458	.453	.712	.453
ratio of means	1.57		1.08		.989		.636	
Nitrate + Nitrite-N								
min	.44	.24	.48	.005	.7	.005	.3	.005
max	1.56	.95	1.64	.85	1.93	.82	3.07	.82
mean	.875	.457	.892	.445	1.178	.4	1.224	.4
ratio of means	.522		.499		.340		.327	
Phosphorus								
min	.35	.005	.28	.005	.31	.002	.42	.002
max	.85	.05	.83	.07	1.48	.04	1.58	.04
mean	.558	.014	.579	.022	.724	.018	.776	.018
ratio of means	.025		.038		.025		.023	
Lead								
min	.13	.005	.24	.005	.09	.001	.12	.001
max	1.11	.06	1.25	.03	.52	.034	.43	.034
mean	.537	.042	.615	.034	.199	.020	.201	.020
ratio of means	.078		.055		.102		.100	
Copper								
min	.01	.001	.012	.0025	.01	.0025	.03	.0025
max	.07	.128	.08	.08	.12	.09	.22	.09
mean	.037	.018	.043	.029	.045	.023	.07	.023
ratio of means	.486		.674		.511		.329	
Iron								
min	1.09	.002	2.0	.0025	.51	.0025	1.01	.0025
max	8.55	.12	9.38	.103	7.1	.12	6.49	.12
mean	4.07	.034	4.16	.029	2.33	.046	2.13	.046
ratio of means	.008		.007		.020		.022	

concentrations of the six constituents in wet fallout and runoff for the four sites. It also contains the ratios of the mean wet fallout concentrations to the mean EMCs, which demonstrate what portions of the constituents in runoff are attributable to rainfall sources. This shows that the greatest part of the ammonia-nitrogen and substantial amounts of the nitrate-nitrite nitrogen and copper in runoff are supplied by rainfall. It is further apparent that the contribution of wet fallout to the other constituents is only a very small fraction of the total observed in runoff.

Recent work at ISWS has involved the determination of temporal variation in pollutant concentrations of rainfall through storms. In a 1980 report[14] the results of sequential sampling of rainfall during a storm showed that concentrations of nitrate, sulfate, calcium, and magnesium varied inversely with rainfall intensity. The concentrations were high at the start of the event, but as the storm progressed and intensity increasd, concentrations dropped to values as low as 10 percent of the initial levels. Toward the end of the storm, as the rainfall intensity diminished, the constituent concentrations began to return to the levels seen early in the storm. For the same event pH varied directly with rainfall intensity.

Wet fallout samples in the NURP project were gross samples, representing the rainfall of an entire event without accounting for variations in pollutant concentrations through the storm. Runoff quality sampling, though, was dependent on a minimum depth of flow at the sampler intake and a minimum time increment between samples. These constraints were necessary to provide sufficient sample volume for lab analysis and, in the case of discrete sampling, to permit the development of an event profile of constituent concentrations. However, these constraints may also have allowed the runoff containing the higher atmospheric contributions to pass unsampled before adequate depth for sampling had been attained. Furthermore, storm runoff in the latter part of an event often went unsampled when all the sample bottles had been filled or when the depth of flow fell below the threshold level. Thus runoff from the period of the storm when pollutant concentrations in the rainfall were recovering could have been incompletely sampled or missed entirely. This suggests that the EMCs in table 6.16 are lower than they ought to be and that the ratios of wet fallout concentrations to EMCs should be lower. It also indicates one reason why the ratio exceeds 1.0 for ammonia-nitrogen on Mattis North.

The acidity of the wet fallout, measured as pH, was not included in the tables. Of the values determined for all three sites, the lowest was 2.5, the highest 8.2. A trend appeared in the results from 1980: in March-April and September-October pH was generally above 5.0, while in May-August pH was usually in the range 3.0-5.0. The values around 3.0 seem low but they are consistent with regional acidity in rainfall. In 1981 the trend was less distinct but essentially the same for two of the three sites.

Table 6.17 is a summary of dry fallout results from 21-24 samples on each basin. The laboratory results expressed in mg/l (with a fixed amount of water added to each sample as solvent) were converted to average deposition rates in mg/m^2/day by incorporating the dry day period associated with each sample. The contents of the table include for ten constituents the maximum, minimum, and average deposition rates calculated for all samples with concentrations reported above detection limits. It appears that dry atmospheric deposition represents an insignificant contribution to the total street loads of the listed constituents, but that it might be a significant input to the load in fines of any constituent on any basin.

Table 6.17 Dry Deposition Quality Summary

MATTIS NORTH

Constituent	min	max	avg	No. of averaged results	No. of trace results
Ammonia-N	0.006	1.14	0.41	20	0
Nitrate/Nitrite-N	0.07	1.16	0.47	17	0
Phosphorus	0.007	0.61	0.14	20	0
Lead	0.008	0.14	0.04	13	8
Copper	0.001	0.11	0.02	17	4
Iron	0.015	0.76	0.24	21	0
Manganese	0.002	0.08	0.02	20	1
Calcium	2.8	13.2	4.87	17	0
Magnesium	0.15	1.9	0.68	15	2
Sodium	0.06	0.24	0.16	10	7

Total Samples = 21

MATTIS SOUTH

Constituent	min	max	avg	No. of averaged results	No. of trace results
Ammonia-N	0.004	0.47	0.12	19	1
Nitrate/Nitrite-N	0.114	0.57	0.30	16	1
Phosphorus	0.006	0.78	0.07	21	0
Lead	0.002	0.05	0.03	7	15
Copper	0.001	0.10	0.02	19	3
Iron	0.002	0.32	0.09	22	0
Manganese	0.001	0.26	0.02	22	0
Calcium	0.81	5.08	2.06	18	0
Magnesium	0.094	0.90	0.25	13	5
Sodium	0.02	0.18	0.11	9	9

Total Samples = 22

JOHN SOUTH

Constituent	min	max	avg	No. of averaged results	No. of trace results
Ammonia-N	0.04	0.43	0.17	22	0
Nitrate/Nitrite-N	0.15	0.86	0.32	19	0
Phosphorus	0.008	0.36	0.09	22	0
Lead	0.003	0.05	0.02	14	10
Copper	0.001	0.26	0.04	18	6
Iron	0.015	0.65	0.16	24	0
Manganese	0.003	0.11	0.02	24	0
Calcium	0.37	5.68	2.45	20	0
Magnesium	0.16	1.07	0.38	17	3
Sodium	0.048	0.163	0.11	11	9

Total Samples = 24

All constituent values in $mg/m^2/day$

Table 6.18 shows a comparison of the loads in mg of nine constituents in five sets of concurrent wet, dry, and bulk fallout samples from the John South basin. The contention that bulk fallout sampling is an adequate substitute for separate wet and dry sampling was tested by comparing the sums of the constituent loads in the wet and dry samples to the loads in the bulk samples. Reasonable correspondence was shown in most cases. However, due to the tendencies for some constituents to arrive principally in wet fallout and others in dry fallout, it is still desirable, if possible, to keep the two portions separate in atmospheric deposition sampling.

Table 6.18 Comparison of Bulk Deposition to Wet plus Dry Deposition
John South basin - 1980

EVENT	RAIN (in)	DRY DAYS	SAMPLE TYPE	CONSTITUENT LOADS IN SAMPLES (mg)									
				NH_3	NO_{2-3}	P	Pb	Cu	Fe	Mn	Ca	Mg	Na
15	0.57	11	Wet	0.28	0.24	0.01	LT*	LT	0.02	LT	LT	LT	LT
			Dry	0.07	0.16	0.12	0.01	0.003	0.15	0.02	1.90	0.36	LT
			ΣW+D	0.35	0.40	0.13	0.01	0.003	0.17	0.02	1.90	0.36	LT
			Bulk	0.33	0.38	0.15	0.02	0.05	0.26	0.03	2.35	0.47	LT
17	0.61	3	Wet	0.18	-	LT	LT	0.02	0.01	LT	-	-	-
			Dry	-	-	-	LT	0.02	0.06	0.01	-	-	-
			ΣW+D	0.18	-	LT	LT	0.04	0.07	0.01	-	-	-
			Bulk	0.24	-	0.01	LT	LT	0.03	LT	-	-	-
19	0.39	3	Wet	-	-	-	LT	LT	0.01	0.001	LT	LT	LT
			Dry	-	-	-	LT	0.02	0.01	0.002	0.36	0.04	LT
			ΣW+D	-	-	-	LT	0.02	0.02	0.003	0.36	0.04	LT
			Bulk	-	-	-	LT	0.02	0.02	0.003	0.39	LT	LT
20	0.32	3	Wet	0.14	0.11	0.01	LT	LT	LT	LT	-	-	-
			Dry	0.04	0.03	0.01	LT	LT	0.03	0.002	-	-	-
			ΣW+D	0.18	0.14	0.02	LT	LT	0.03	0.002	-	-	-
			Bulk	0.25	0.14	0.03	LT	LT	0.02	0.003	-	-	-
24	0.96	6	Wet	0.32	0.46	LT	LT	LT	LT	LT	LT	LT	LT
			Dry	0.03	0.06	0.03	LT	0.02	0.05	0.004	0.59	0.10	LT
			ΣW+D	0.35	0.52	0.03	LT	0.02	0.05	0.004	0.59	0.10	LT
			Bulk	0.31	0.52	0.03	LT	0.03	0.06	LT	0.79	LT	LT

All values in mg.

*LT= constituent value reported by lab less than detection limit

SECTION 7

DISCUSSION

At this time, urban storm runoff remains a water quality problem of indefinite dimensions. Constituent concentrations and runoff flow rates vary rapidly and drastically during events. For many constituents, concentrations well above general use water quality standards may appear in runoff. Yet the appropriateness of the application of such standards to urban runoff is questionable. Standards generally identify limits for continuous, or at least long-duration, constituent levels, but urban runoff is intrinsically intermittent and constituent concentrations are transient. Furthermore, standards customarily refer to constituents in states that are wholly available to assimilation by aquatic life forms, but many constituents in urban runoff are largely associated with solids and are not immediately available for uptake. So while the concentrations and loads of constituents in urban runoff may be substantial, their effect on aquatic life is uncertain. Water quantity rather than quality may be the principal concern in urban streams. The severe fluctuation of water levels in streams conveying urban runoff may have negative influences on aquatic habitats. It may also cause scour and transport of stream bottom materials on occasions of more severe storms. It is possible that water quality effects of urban runoff are not evident until the constituent loads arrive in some receiving water, such as a lake, a reservoir, or a slow-moving larger stream. Deposition of solids loads from runoff could then occur, and constituents associated with the solids could begin to influence aquatic life. The 1982 study of impacts of urban runoff on receiving

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streams in Champaign-Urbana was intended to investigate some of these possibilities, and its report will deal with them in greater depth.

The idea of street sweeping as a management practice for urban storm runoff quality seems sound. If street load is a major source of runoff pollutants, and street sweeping is employed to remove some portion of that load, then some reduction of pollutant concentrations or loads ought to appear in subsequent runoff. In this study the removal of significant portions of street load by sweeping was demonstrated by measuring both the material picked up by the sweeper and the load left on the basin after sweeping. The lack of consequent improvement in runoff quality is a puzzle in which many factors may have a share.

Foremost among these factors is the predominance of fines in runoff solids. The data obtained in this study on particle size in runoff suggest that fines constitute the greatest part of solids in runoff for most events. Mechanical street sweepers are designed to control and collect litter and large material from streets. Their efficiency in collection of fine material is demonstrably low. A vacuum-assisted street sweeper might do a better job of removing fines from streets, but none was available for this study. Another NURP project did test the performance of a vacuum-assisted sweeper, but the results are not known.

Local characteristics of streets, especially conditon and texture of the surfaces, may be the limiting factor in sweeper performance. Certainly recommendations can be made for any sweeper or group of sweepers to enhance performance to a maximum. Route layouts, numbers of single or tandem passes, operation criteria, and maintenance schedules can be developed to extract the optimum performance from a machine. Yet irregularities of pavement and curb may undermine the effect of employing such practices.

The collection of fines from a rough-textured street with a mechanical sweeper could be very difficult even with the use of optimum sweeping procedures.

Other aspects of sweeping and street load may contribute to the runoff quality problem. Under moderate to heavy street loading conditions, the action of the sweeper may cause the disintegration of larger particles and aggregates into fines which are not collected but are easily washed off. The sweeper brooms may also loosen material adhering to the street, making material available to washoff which otherwise might have remained attached to the street through an event. In either case, the action of the sweeper would be simultaneously to collect solids from the street and to leave behind solids for washoff. Another function of sweeping, which appeared to have occurred on the residential basin in the fall, might be to remove material from the gutter which would otehrwise have impeded flow and dimininshed the load the runoff could carry. With the obstructing material gone from the gutters and inlets, the runoff could carry the remaining solids more freely from the street to the sewer.

It is important to recognize that street load is not the only source of runoff pollutants. Rainfall can supply appreciable fractions of several constituents and nearly all of some, such as ammonia-nitrogen and nitrate-nitrite nitrogen. Whether air pollution controls could have a significant impact on reduction of atmospheric contribution is arguable. More would have to be known about individual and nonpoint sources of atmospheric pollutants before any degree of confidence could be reached in plans for controlling them. Directly connected impervious areas other than streets, such as parking lots and some roofs and driveways, will add to storm runoff for most events, though they are rarely sampled or cleaned. Less frequently, other areas such as lawns and roofs which drain onto lawns may also contribute to flows and loads. Local conditions in storm sewers may allow them to serve as sources or sinks of pollutants. Especially in areas of flat terrain, like Champaign, small storms may permit the movement of material form the streets to the sewers, where it may be deposited in the lines or manholes. When this has happened, subsequent larger storms can scour the deposited material from the system and transport it along with new material from the surface. This can increase the difficulty of developing a mass balance of material on a study basin.

Finally it is important to acknowledge the influence of error in measurement on the findings of this study. In a sampling program of this extent the possibilities for error introduction are numerous. Aspects of event monitoring subject to error include representation of basin rainfall by point rainfall measurement, measurement of runoff water levels, conversion of stage to flow using rating curves, representation of runoff quality with automatic sampling through a fixed intake, and representation of runoff loads by automatically-controlled flow-weighted composite sampling. Possible sources of error in the street dirt sampling program included representation of the load on the pavement by the vacuumed sample and on the basin by the composite of subsamples as dictated by the experimental design, the determination of the particle size distribution of the street load by analysis of one small portion split from the basin sample, and the determination of quality by particle size of load from a basin using composites of several days' worth of samples for each size group. Still other error sources could exist in the street sweeping program as designed by ISWS and practiced by the City of Champaign, including completeness of operation in a basin, accuracy of weighing of load removed from a basin, and representation of the sweeper hopper contents with a single subsample. The cumulative effect of errors in these areas of data collection could have enormous impact on the findings. However, ISWS has been diligent in searching for errors and refining summaries, so that the data set developed during the study and the analyses based on it are believed to be the best possible information from the raw data.

The primary objective and additional goals of the project, as set forth in Section 1, have fundamentally been accomplished. For the conditions tested, municipal street sweeping was shown to be ineffective as a management practice for improvement of urban storm runoff quality. Deposition and accumulation of street dirt were defined in Section 6 for the study basins and generally for the land use types they represented. The individual influences of traffic and street type and condition on deposition and accumulation could not be identified. The washoff of street dirt was defined in Section 4 in terms of rainfall, slope and roughness of street surface, and amount and size distribution of load on the street, and the result was incorporated into the Q-ILLUDAS model. The modified model was calibrated on the study basins, as reported in Section 4, and the results used in this analysis. The contribution of wet fallout to runoff quality was determined and documented in Section 6. Production functions and cost functions for total solids only were developed for one residential basin and one commerical basin in Section 6. The failure of street sweeping to demonstrate any effectiveness in controlling urban storm runoff quality made development of additional functions a futile exercise.

SECTION 8

CONCLUSIONS

1. Mechanical street sweeping at frequencies as great as twice weekly is not effective in reducing the mean concentration or total load of pollutants in urban stormwater runoff. This conclusion is valid within the constraints of this study which must include the geographical location and its associated weather patterns, the pollutants studied, the type and condition of sweeper, the street surface material and condition, the slope of the street surfaces, traffic volume, and land use. Indications of increases in the concentration or load of pollutants during sweeping were at least as strong as were indications of reduction.

2. Mechanical street sweeping at a frequency equal to or greater than once per week reduces the amount and variability of street dirt. Tests were conducted on asphalt and concrete streets in good condition in four urban basins with two land use types and three general loading ranges. After a period of sweeping at a given frequency, the particle size distribution of the street load in an area will gradually shift toward a greater fraction of fines and a smaller fraction of coarse material.

3. The mechanical street sweeper used in this study demonstrated an overall removal efficiency ranging from 30 to 67%. The effectiveness of street cleaning with a mechanical sweeper depends not only on the operation of the machine but also on the load and particle size distribution of material on the street before sweeping. A mechanical sweeper generally performs more efficiently in removing coarse material than fine material, though performance depends on the total and relative amounts of each in the

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initial load. For any urban area, a frequency of sweeping can be determined beyond which additional sweeping effort will not produce any further reduction of street load.

4. Wet deposition is apparently the major source of several constituents of concern in urban runoff. Rainfall contributions may account for 64-100% of ammonia-nitrogen, 33-52% of nitrate-nitrite nitrogen, and 33-67% of copper concentrations seen in storm runoff. For other constituents the portions of runoff concentrations attributable to rainfall are smaller: 6-15% of lead, 2-4% of phosphorus, and 1-2% of iron. For any constituent, the fraction of total runoff loads conveyed into the urban area by precipitation cannot be controlled by any management practice except treatment.

5. In all four basins the greatest percentage of total street load, if the gross material larger than 2000μ is excluded, falls in the size range 250-500μ. For the constituents of major interest, concentrations in size groups below 1000μ tend to increase with decreasing size, reaching a maximum in the 63-125μ group and falling off in the fines. Combination of these two sets of data shows that the greatest part of the load of a constituent in the total street load exists in the 250-1000μ material. Removal of particles in these size ranges would control the bulk of the load of most constituents of concern.

6. Virtually 100% of the ammonia-nitrogen and nitrate-nitrite nitrogen in storm runoff is dissolved and has no apparent relationship with solids. For other constituents the dissolved fraction is less: Kjeldahl nitrogen,

69%; phosphorus, 43%; copper, 32%; manganese, 27%; iron, 2%. Lead and nickel appear to be wholly associated with solids.

7. Hydrologic simulation with Q-ILLUDAS provides correlations with observed flows of .90 to .95. Water quality simulation is much less reliable with correlations in the range of .65 to .85 depending on the constituent.

The high rating of the hydrology simulation is due to the relationship of the simulated hydrograph shapes, volumes, peaks, peak times, and event runoff coefficients to those of the observed data.

The moderate rating of the water quality is due to the generally fair simulation of constituents related to the appearance of coarser sediment, although the simulation of constituents highly related to the appearance of fines was good. The implication, so far as the simulation is concerned, is that the representative diameters chosen to represent the surface load and eventual washoff loads are over-representative of the smaller particles. Optimization is needed for more effective representation of the accumulation and removal of larger particles and the washoff of their related water quality constituents.

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APPENDIX I
Q-ILLUDAS DOCUMENTATION

ILLUDAS

In 1974, as a result of an investigation of various methods of predicting surface runoff from urban rainfall, the Illinois State Water Survey released ILLUDAS, the Illinois Urban Drainage Area Simulator (Terstriep and Stall[1]). The model, capable of simulating single rainfall events on a user-defined basin, has become a widely used urban runoff model. Several of the model's attributes have led to this popularity: small input data requirements, relatively small core requirements, low run costs, the use of well-documented empirical functions, no-cost maintenance and support from ISWS, and results which are comparable to other more detailed and expensive models, such as SWMM (Han and Rao[4]). ILLUDAS may be used to evaluate existing drainage systems, to design new drainage systems, or be used in both capacities simultaneously, such as generating commercially available pipe sizes for reaches where existing pipes are undersized.

ILLUDAS accepts the identification of three basic land surface cover types for a subcatchment: directly connected paved areas (CPA), such as roadways and parking lots; contributing grassed areas (CGA), which are those pervious areas that are deemed to be significant in their contribution to the subcatchment runoff, such as front yards; and supplemental paved areas (SPA), which are areas such as sidewalks and residential rooftops whose runoff does not have a completely impervious flow path to the inlet but must flow across some pervious area. For a particular subcatchment, the rainfall over SPA is uniformly distributed over and added to the rainfall for CGA. During surface runoff on impervious areas, Manning's equation with a fixed hydraulic radius is used to determine the paved area time of concentration. This time of concentration and its ratio to the selected routing interval is utilized to create an iso-chronal distribution of the tributary area about the flow path. This distribution forms a piecewise convolution algorithm for surface runoff. Grassed areas are similarly routed by determination of the grassed surface time of concentration added to the paved area entry time.

Channel routing may be done either by a simple time shift storage routing technique, or by an algorithm which generates an implicit solution to the continuity equation. The user may estimate required storage volumes for specific maximum reach discharges, or estimate the reach discharge required to generate a specific volume of storage. The former has been quite helpful in studies where zoning laws require the runoff under developed conditions not to exceed that of pre-development conditions.

Q-ILLUDAS

Many hydrologic investigations require the analysis of a continuous historical record, such as the determination of flow duration curves, prediction of the expected number and duration of water quality standard violations, and the evaluation of the benefits one might accrue due to a proposed "best management" practice. Since most continuous simulation models require large amounts of data, computer core, and money, it was decided that there is a need for such a model that would require substantially less of all these. Q-ILLUDAS, a continuous rainfall/soil moisture processing version of ILLUDAS, is the result of this enterprise. The new model, aside from having new algorithms for continuous accounting of soil moisture storage, has also had many of the algorithms of the prececessor model changed or replaced. Among the features which were changed are the computation of concentration time, elimination of the repetitious rainfall processing between reaches, elimination of the assumption that all abstractions must be fully satisfied before runoff can occur, elimination of the assumption that runoff from SPA affects 100 percent of CGA, and elimination of the exponential washoff equation used by QUAL-ILLUDAS.[2] The following discussion will more specifically address these changes and the new algorithms.

Model Features and Algorithms

Q-ILLUDAS operates on three time steps. On dry days, percolation, infiltration from depression storage, and evapotranspiration from moisture storages occur at a daily rate. On a day with rainfall, the above processes occur at an hourly rate during dry hours. During wet hours, dry intervals and rainfall/soil moisture algorithms are processed at a user-specified time step (1, 2, 5, 10,...minutes). The actual processing hierarchy is shown by the flow chart in Figure 1. For the sake of discussion, the user-specified interval will be set at one minute.

Land Cover Type Descriptions

The same three land cover types as previously discussed are used by the new model; but, rather than processing SPA and CGA as one surface type, a fourth cover type, processed independently of CGA, is generated to represent that portion of the pervious area affected by runoff from SPA. This new surface/soil profile is referred to as the affected grassed area (AGA). This area is assumed to be at most twice the size of SPA, and will be less if CGA is not at least twice as large as SPA. The acreage under CGA is reduced by the acreage assigned to AGA. As one can see in Figure 2, the previous treatment of SPA/CGA misrepresented the grassed area runoff to the extent that the rooftop, driveway, and sidewalk runoff affected the entire pervious area. This simplification tends to overestimate the runoff from areas not really affected by runoff from SPA, and underestimate the soil saturation and runoff from areas which were affected. The new method processes rainfall on SPA for impervious depression storage, and then uniformly distributes the resulting hyetograph over the AGA, along with the rainfall falling directly on AGA, which has been abstracted for interception storage of the canopy. From this point on, runoff is processed for two pervious surface covers, CGA and AGA.

Rainfall/Soil Moisture Processing Hierarchy

In the simulation of a particular catchment's hydrology, any combination of two raingages and two soil types may be used. In order to avoid

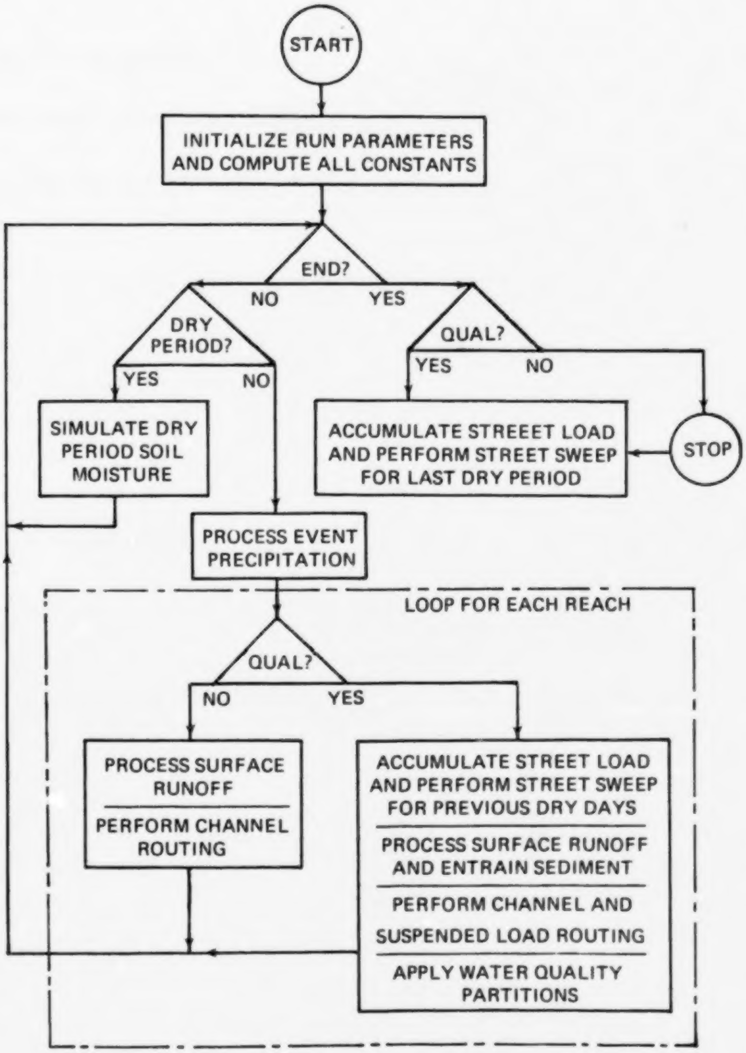
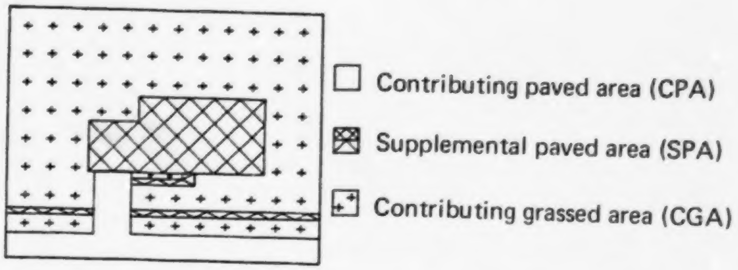
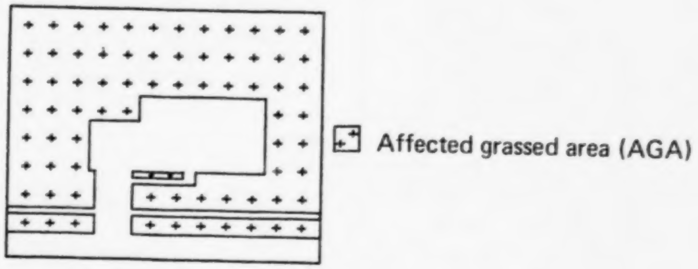

START
INITIALIZE RUN PARAMETERS AND COMPUTE ALL CONSTANTS
END?
NO
YES
DRY PERIOD?
YES
NO
SIMULATE DRY PERIOD SOIL MOISTURE
QUAL?
YES
NO
ACCUMULATE STREEET LOAD AND PERFORM STREET SWEEP FOR LAST DRY PERIOD
STOP
PROCESS EVENT PRECIPITATION
LOOP FOR EACH REACH
QUAL?
NO
YES
PROCESS SURFACE RUNOFF
PERFORM CHANNEL ROUTING
ACCUMULATE STREET LOAD AND PERFORM STREET SWEEP FOR PREVIOUS DRY DAYS
PROCESS SURFACE RUNOFF AND ENTRAIN SEDIMENT
PERFORM CHANNEL AND SUSPENDED LOAD ROUTING
APPLY WATER QUALITY PARTITIONS

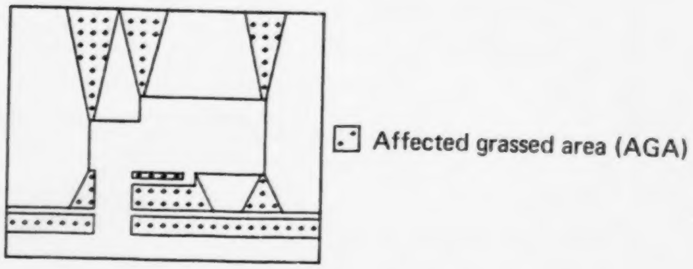
Figure 1. Flow diagram of Q-ILLUDAS


Contributing paved area (CPA)
Supplemental paved area (SPA)
Contributing grassed area (CGA)

(a) GENERAL SURFACE COVER DEFINITION


Affected grassed area (AGA)

(b) PREVIOUS TREATMENT OF SPA BY ILLUDAS


Affected grassed area (AGA)

(c) NEW TREATMENT OF SPA BY Q-ILLUDAS

Figure 2. Treatment of supplemental paved area (SPA)

the repetitious processing of rainfall, the new model pre-processes each hydrologic soil group/raingage combination before deciding whether or not the expected basin runoff will exceed the user-supplied minimum volume required for routing. During dry periods, the following order is used to process soil moisture and above ground water storage: evaporation from interception storage; evaporation and infiltration from depression storage; evapotranspiration and deep percolation from soil moisture storage. All of these processes incorporate the spatial distribution described later. Wet periods are processed following the same hierarchy as above. On impervious surfaces, depression storage is the only abstraction considered.

All of the above processes are assumed to be spatially distributed, and are simulated by the use of a triangular distribution. Figure 3a shows that the distribution is assumed to vary linearly from zero to twice the user-specified mean value over the subcatchment area. DEPG, as an example, is the mean pervious depression storage. Figure 3b shows the concurrent processing of depression storage and infiltration potential. Although both the filling of depression storage and infiltration are assumed to be spatially distributed as in Figure 3a, they are assumed to be totally independent of one another physically. Depression storage may, therefore, be considered to have a uniform distribution with respect to infiltration potential.

As shown in Figure 4a, there are four basic state variables required to define the current status of any process or storage: MAX, which is two times the mean value; NX1, the current storage curve intercept; NX2, the current maximum depth in storage; and STO, which is the current total volume in storage. S represents the moisture supply depth in the current minute. Figure 4b shows the change in the values of parameters NX1, NX2, and STO as a result of this moisture supply. E represents the excess moisture supply. The processing of losses may be illustrated using Figure 4a. If we allow S to represent the evapotranspiration potential during the minute, the volume of STO below S is assumed to satisfy part of the potential and the values of NX1 and NX2 are lowered by S. The volume below S and to the left of the storage curve NX1 at the start of the minute is unsatisfied potential and is passed on to the next process.

The concurrent processing of infiltration and depression storage, Figures 5a and 5b, assumes that infiltration potential, varying from zero to 2FINC, is satisfied for a particular level of supply, S, before considering depression storage. The supply rate is the sum of the rainfall after interception losses and the uniformly distributed volume of depression storage at the start of the interval. This assumption allows for infiltration from both depression storage and from surface storage. The volume below S and between the curves 2FINC and MAX represents the moisture supply to depression storage in the interval, D, and is processed according to the above discussion of Figures 4a and 4b. The volume remaining below S and above the curve bounded by MAX is the surface runoff volume for the minute.

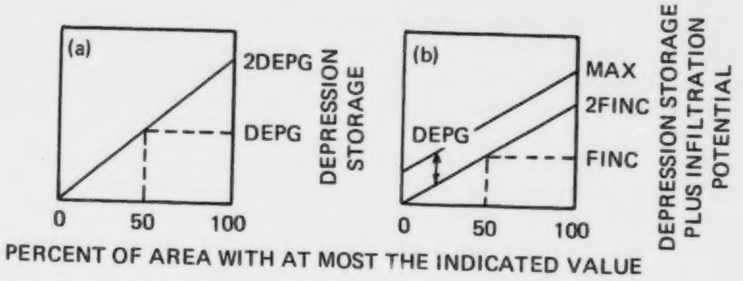

(a)
2DEPG
DEPG
DEPRESSION STORAGE
0
50
100
(b)
MAX
2FINC
DEPG
FINC
0
50
100
DEPRESSION STORAGE PLUS INFILTRATION POTENTIAL
PERCENT OF AREA WITH AT MOST THE INDICATED VALUE

Figure 3. Spatial distribution definitions: a) basic distribution, b) concurrent depression storage and infiltration potential

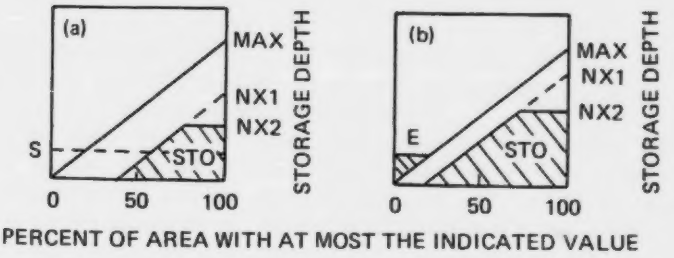

(a)
MAX
NX1
NX2
S
STO
0
50
100
STORAGE DEPTH
(b)
MAX
NX1
NX2
E
STO
0
50
100
STORAGE DEPTH
PERCENT OF AREA WITH AT MOST THE INDICATED VALUE

Figure 4. Storage gain using spatial distribution: a) start of interval, b) end of interval

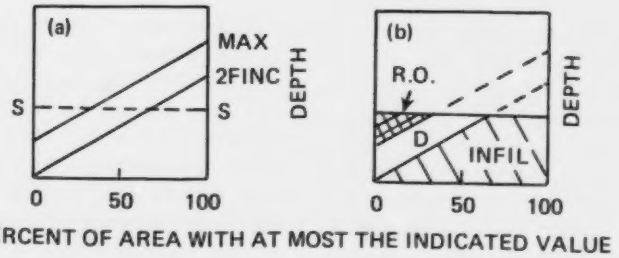
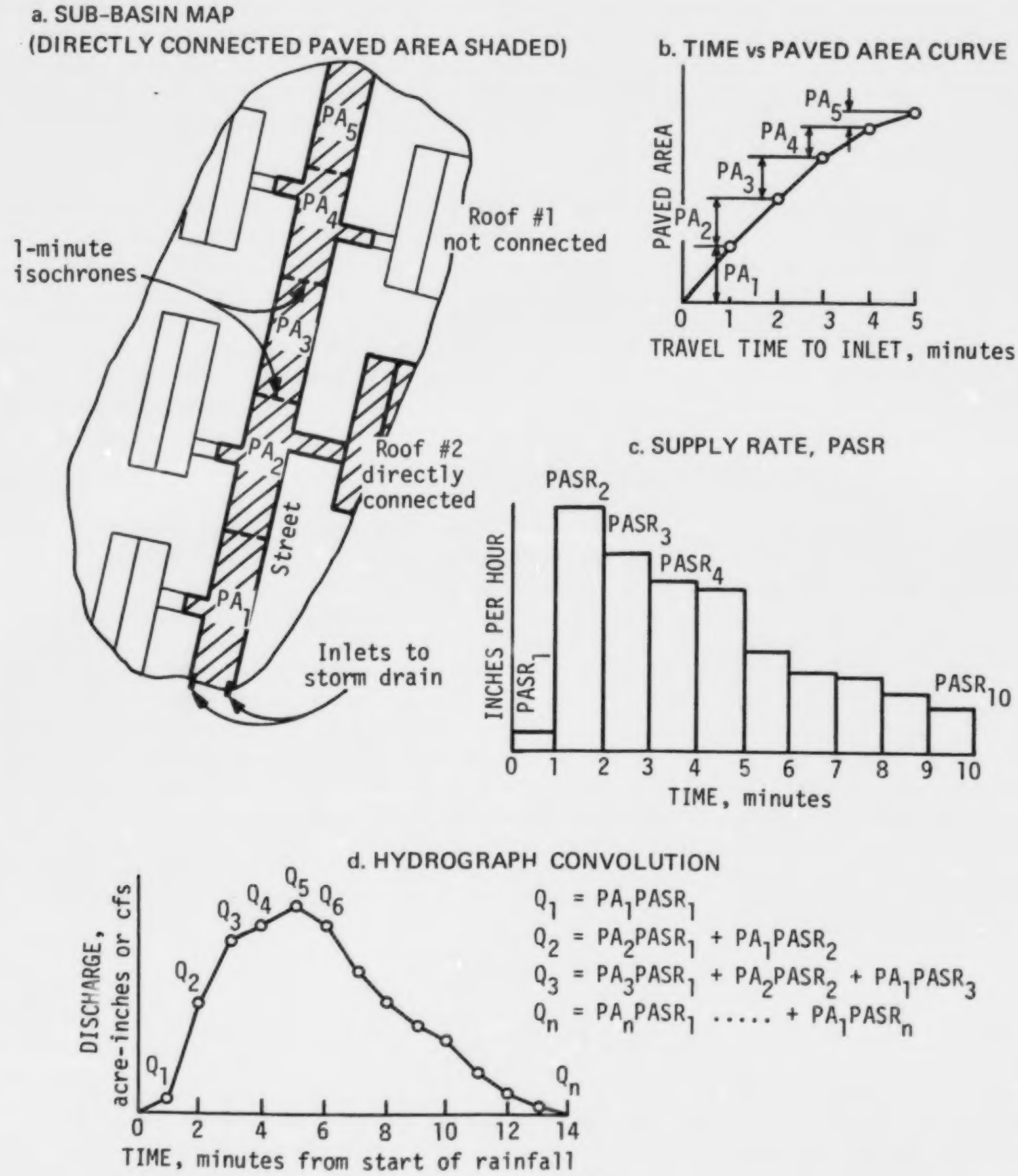

(a)
MAX
2FINC
S
S
0
50
100
DEPTH
(b)
R.O.
D
INFIL
0
50
100
DEPTH
PERCENT OF AREA WITH AT MOST THE INDICATED VALUE

Figure 5. Concurrent processing of moisture supply to depression storage and infiltration: a) inputs, b) outputs


a. SUB-BASIN MAP (DIRECTLY CONNECTED PAVED AREA SHADED)

b. TIME vs PAVED AREA CURVE

c. SUPPLY RATE, PASR

d. HYDROGRAPH CONVOLUTION

$$Q_1 = PA_1 PASR_1$$
$$Q_2 = PA_2 PASR_1 + PA_1 PASR_2$$
$$Q_3 = PA_3 PASR_1 + PA_2 PASR_2 + PA_1 PASR_3$$
$$Q_n = PA_n PASR_1 \ldots\ldots + PA_1 PASR_n$$

PA5
PA4
Roof #1 not connected
1-minute isochrones
PA3
PA2
Roof #2 directly connected
Street
PA1
Inlets to storm drain
PAVED AREA
PA5
PA4
PA3
PA2
PA1
0 1 2 3 4 5
TRAVEL TIME TO INLET, minutes
INCHES PER HOUR
PASR1
PASR2
PASR3
PASR4
PASR10
0 1 2 3 4 5 6 7 8 9 10
TIME, minutes
DISCHARGE, acre-inches or cfs
Q1
Q2
Q3
Q4
Q5
Q6
Qn
0 2 4 6 8 10 12 14
TIME, minutes from start of rainfall

Figure 6. Elements in development of paved area hydrograph by time-area method:
a) sub-basin map (CPA shaded)
b) time vs. paved area curve
c) supply rate (PASR)
d) hydrograph

Land Surface Processes

The processing of surface runoff by the model is undertaken only if the approximate runoff volume of the event will exceed a user-defined minimum value. The surface runoff for a particular subcatchment is generated utilizing the pre-processed effective hyetographs along with the physical parameters of the area. It is assumed that all front yard runoff will be routed overland to the street and be uniformly distributed along the roadway's length. Backyard runoff may also be routed to and over the street, or it may be assumed to run off directly to a drain via the back lot line. There are two surface routing methods available in Q-ILLUDAS which will now be discussed.

Time Area Distribution. This is the method which is used by ILLUDAS, for both impervious and pervious areas, with one major change. This is a linear convolution method in which the time of concentration is used to determine isochrones, or, in other words, to develop a contour map of the catchment whose intervals are time to inlet in minutes. The algorithm uniformly distributes the tributary area about the longest flow path, and aggregates the outfall hydrograph as shown in Figure 6. The only change made in this algorithm is the use of the kinematic wave equation to compute the concentration time for all surfaces. The kinematic wave equation is:

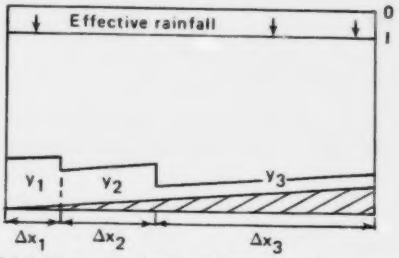
$$tc = 0.94\ (L\ n/\sqrt{S})^{0.6}/i^{0.4} \qquad (1)$$

where tc is the time of concentration, in minutes; L is the overland flow length, in feet; n is Manning's roughness; S is the surface slope, in ft/ft; and i = moisture supply rate, in in/hr.

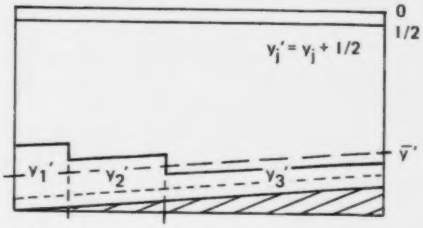
Kinematic Wave Generator. Although the above method generates acceptable results from the standpoint of runoff volume, runoff timing, and overall hydrograph shape, close inspection reveals that the peak time tends to lag a bit, and radical changes in the slope of the hydrograph tail are common. These factors are the result of assuming a constant velocity for surface runoff throughout the event. This causes slower than observed response at high discharge rates, and faster than observed responses at the relatively low rates. An attempt has been made to remove these biases by allowing a modified kinematic wave to develop on the surface. This method, shown in Figure 7, computes the value of tc_i, the time of concentration for the i^{th} minute, as

$$tc_i = 0.94\ (L\ n/\sqrt{S})^{0.6} \Big/ \left[(I_i/2) + \frac{1}{L}\sum_{j=1}^{N}\left\{(x_{j,i-1})d_{j,i-1}\right\}\right]^{0.4} \qquad (2)$$

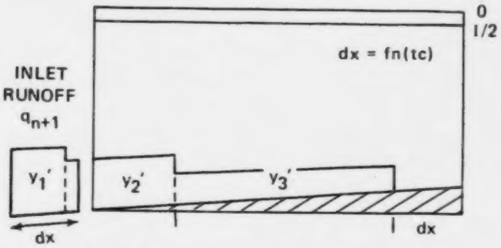
where I_i is the effective hyetograph ordinate for the i^{th} minute, N is the number of differential depths on the flow plane, $d_{j,i-1}$ is the average depth at the end of the last minute for sector j of the kinematic wave, and $x_{j,i-1}$ is the length of sector j at the end of the last minute. By allowing tc_i to vary based on both the current surface storage and the current input to surface storage, the surface runoff velocity varies with increasing or decreasing depth on the flow


Effective rainfall
0
I
y1
y2
y3
Δx1
Δx2
Δx3

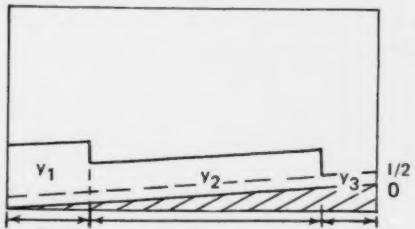
(a) Differential depth of storage and rainfall for time = t_n


0
I/2
y_i' = y_i + I/2
ȳ'
y1'
y2'
y3'

(b) Differential storage plus mean rainfall over current interval, I/z


0
I/2
dx = fn(tc)
INLET
RUNOFF
q_{n+1}
y1'
y2'
y3'
dx
dx

(c) Determine runoff to inlet for interval from time of concentration where tc = fn ($\overline{y}'$)


y1
y2
y3
I/2
0
Δx1
Δx2
Δx3

(d) Modified Kinematic wave at end of interval, time = t_{n+1}

Figure 7. Modified kinematic wave surface routing

plane, thus improving the simulated hydrographs correlation to the observed. Figure 8 shows this improvement, which at first glance may not seem overly significant. But, when water quality is being simulated these improvements, along with the variable runoff velocity, are very important.

Surface Load Accumulation. When water quality is being simulated, the model determines the elapsed time since the last event ended. The linear accumulation function,

$$PLOAD_{j,n} = PLOAD_{j,n-1} \, (1-r_j) + Fall_j \, (K) \qquad (3)$$

is then utilized to approximate the accumulation of street dirt in each of the five size groups, designated by subscript j.[5] In the above equation, $PLOAD_{j,n}$ is the surface load of particles in group j at time t=n, in kg; r_j is the natural removal rate due to wind, decay, etc., in kg lost per kg load per day; $Fall_j$ is the accumulation rate for group j, in kg per day per curb-kilometer; and K is the number of curb-kilometers in the subcatchment. If street sweeping is being simulated, the model reduces the surface load in each size group according to user specified sweeper removal efficiencies.

Surface Load Removal. The concept of modeling water quality as a function of surface sediment load removal is not an original concept. The NPS model utlizes sediment removal and applicable constituent partitions to generate pollutant loads.[5] The NPS model, however, looks only at gross sediment removal utlizing the exponential washoff equation. Washoff pollutographs generated from the sediment load will differ linearly as a function of the partitioning factors. The PTM model also deals with water quality as a function of surface sediment removal, but looks at various size groups within the load.[6] The PTM model utilizes sediment transport equations to determine the sediment removal.

Q-ILLUDAS' sediment removal is based on a series of work equations derived from literature published by Allen, Garde, and draws on the work of Sutherland.[7,8,9] The surface routing and entrainment algorithms approach sediment removal on a micro-scale, with a spatial convolution technique being employed to accumulate basin inlet hydrograph and loadographs from the characteristic hydrograph and loadographs generated by the following techniques.

The water quality algorithms used in Q-ILLUDAS require the use of the kinematic wave surface routing option in order to have variable surface runoff velocities. The model will use this method whether the user has requested it or not during water quality simulation. A typical reach in an urban catchment may have several curb inlets; therefore, it is not practical to model the paved surface runoff as one lumped hydrograph. The model takes a user-specified "characteristic" lane length and width and the number of inlets in the subcatchment to generate a characteristic surface runoff hydrograph and the associated surface runoff loadographs.*

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*The term "loadograph" is used in lieu of pollutograph in this case to describe the time series of suspended load washoff for five size groups.

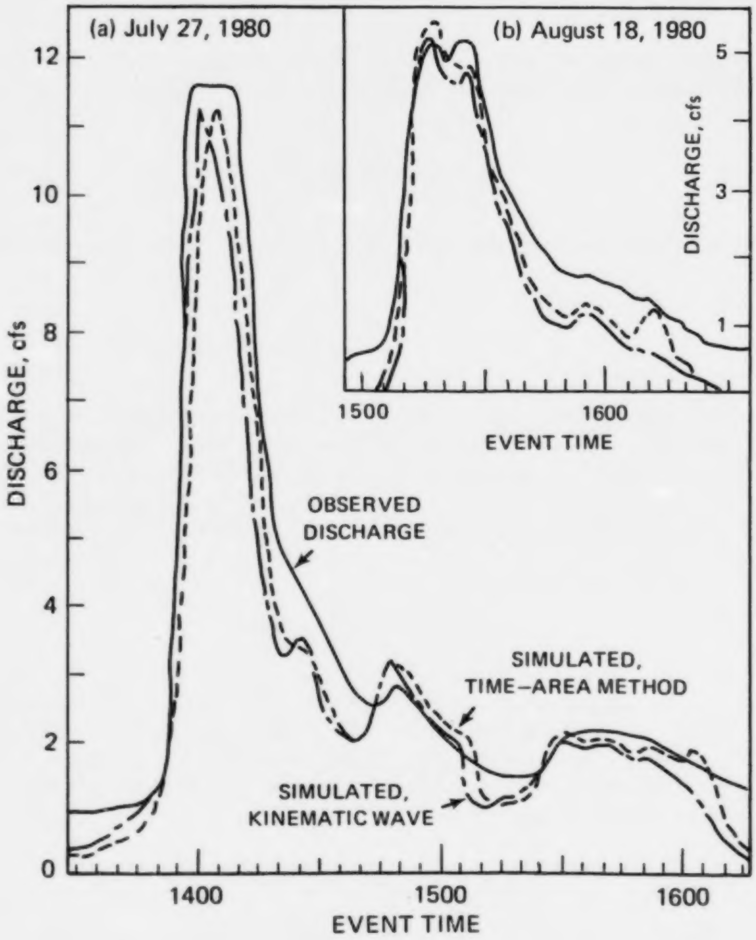

Figure 8. Comparison of surface routing methods - John North basin

The convolution of these characteristic time series of a set of spatially distributed inlet time series will be discussed later.

The movement of particles into and out of suspension is done by balancing a series of work equations. This is done simply by equating the potential of the moving water to the sum of the work it is exerting to move the current suspended load and the work required to entrain and move a fraction of the remaining bed load. If the runoff velocity lessens to the point where the current suspended load required more work than is available, the program allows a portion of the suspended load to settle back to the surface.

Before particles of a particular size group, j, may be entrained with the suspended load, the average boundary shear stress, τ_o, of the flow, given as

$$\tau_o = y\ (\rho_f)\ g \sin\alpha \tag{4}$$

must exceed the critical tractive shear stress, τc_j, for the size group,

$$\tau c_j = \frac{\pi}{6} D_j\ (\rho_j - \rho_f)\ g \cos\alpha(\tan\phi_j - \tan\alpha) \tag{5}$$

where y is the depth over flow plane, ρ_f is the density of water, g is the gravitational acceleration, α is the bed slope, D_j is the mean diameter of particles in group j, ρ_j is the density of particles in group j, and ϕ_j is representative of the packing of particles in the bed load for group j. If $\tau_o \geq \tau c_j$, then the gross work potential of the fluid is determined as

$$POT_n = \tau_{o_n} A_n V_n\ dt \tag{6}$$

where POT_n is the gross work potential of the fluid for the nth minute, A_n is the wetted surface area under the flow, V_n is the surface runoff velocity for time n, and dt is the time interval in seconds. The work currently being done by the fluid to keep particles of group j in the suspended state, $WRKLD_{j,n}$, is defined as

$$WRKLD_{j,n} = SUS_{j,n}(V_n dt + Y_n/2)g/WRKEFF_j \tag{7}$$

where $SUS_{j,n}$ is the total current suspended load of group j at time n, and $WRKEFF_j$ is the efficiency coefficient for the fluids ability to entrain and transport sediment from group j. When equation 7 is summed for the five groups and subtracted from POT_n, the determination of settling or entrainment may be made.

When the difference is positive, entrainment may occur if the average boundary shear is greater than the critical tractive shear for a particular group. There are two limitations on the amount of sediment being entrained, one being the mass which would exactly balance the work equation, $WRKLIM_j$, and the other being the availability of particles from group j on the flow surface, $BLOAD_j$. The determination of the first limit requires the determination of the work that would be required to entrain the entire remaining surface load in group j, which is

$$WRK_{j,n}=PLOAD_{j,n}(V_n dt+Y_n/2)g/WRKEFF_j \qquad (8)$$

in which $WRK_{j,n}$ is the total work required. The limiting value then becomes

$$WRKLIM_j = PLOAD_{j,n} \left[MIN\left\{1,(POT_n-\sum_{j=1}^{5} WRKLD_j)/WRK_j\right\}\right] \qquad (9)$$

The physical availability of particles of a particular size group is a function of the original load and the current load for the event. This limitation is known as "bed armoring", or the pining of some particles beneath particles of significantly larger size. A simple equation used by Alley et al.[6] is

$$BLOAD_{j,n}=PLOAD_{j,n}\ Z_n(1-PLOAD_{j,n}/PLOAD_{j,0}) \qquad (10)$$

where Z_n is the fraction of the flow plane wetted during the nth interval. The actual surface load being entrained for the interval is the minimum of $BLOAD_{j,n}$ and $WRKLIM_{j,n}$.

If the net available potential, $POT_n - \Sigma\ (WRKLD_{j,n})$, is negative, then settling of particles occurs until a zero net is achieved. The settling function weights decrease in suspended load for each group as a function of Stoke's Law of Settling, which states

$$Vs_j = \frac{1}{18}(\rho_j - \rho_f)\ g\ D_j^{\,2}/\mu \qquad (11)$$

where Vs_j is the mean settling velocity for particles of group j, and μ is the viscosity of the fluid.

Channel Processes

The channel processes are governed by one card of parameters per reach. The drainage network is identified by a branch-reach designation system through which the program may keep track of the connectivity of the system. Point sources may now be input for up to twenty-five reaches using daily average discharge rates and daily mean concentrations of modeled constituents. Q-ILLUDAS, as did its predecessor, allows a desired storage volume to be requested for a reach, which results in the generation of a maximum discharge required to generate this volume of storage. The model also accepts a maximum outflow parameter for a reach. If specified, the model will indicate what minimum volume of storage is required to provide this upper limit. This same parameter, when given a negative value, generates a discharge sink, that is, all discharge up to the absolute value of this parameter is removed from the basin, such as might happen if a combined sewer system intersects an urban catchment. In the case of stored volumes of water, the program assumes that complete mixing of the suspended load takes place.

Testing of the implicit routing technique relative to the simple storage routing technique showed that the more time-consuming implicit method really provided no significant improvement over the simple time shifting algorithm, so the implicit method was dropped. The time shift method simply computes the minimum flow-through time for the reach, and determines a shifting factor, NSHIFT, equal to the flow-through time divided by the routing interval. The various time series for the reach are then shifted NSHIFT intervals in time. The routed hydrographs and loadographs are then stored in two vectors which allow up to seven branches to be open at any one time. If it is possible to organize the basin data so as to have less than seven branches open at any time, the user may want to decrease the dimensions of the vectors accordingly. This is because for each branch there are six vectors of 400 elements (a hydrograph and 5 loadographs) requiring a total of 2400 words of storage per branch allowed.

Because characteristic lengths are used to model surface runoff on paved areas, it is necessary to input the resultant inlet hydrographs and loadographs to the reach in a spatially distributed manner. This is done by a method of "backward" or "upstream" convolution which is a function of the inlet locations and the estimated flow-through time of the reach. The estimated flow-through time is a function of the peak of the upstream hydrograph, if any, and two times the local characteristic hydrograph peak. This process generates an upstream hydrograph which, when routed through the reach, will account for the location of inlets along the primary flow path.

Model Output

With respect for the fact that many printers and portable terminals have 80 character record lengths, all output from Q-ILLUDAS has been formatted to a maximum length of 79 characters, to avoid the confusion of records wrapping around to the next line and to avoid unnecssary blank records generated by printing 80 character records on an 80 character machine. The basic information on run parameters is always printed first. The output of hydrologic data will always include event start dates, start times, and outfall hydrographs. By increasing the value of one print switch, more detailed information may be printed for any or all reaches in the basin. This additional output may include the local surface runoff hydrographs, inlet and design peak discharges, reach hydrographs before and after routing, and instantaneous and total surcharge volumes.

When water quality is simulated, a variety of different results are available for both the basin as a whole and for individual reaches. At any level of hydrologic output mentioned above, any combination of loadographs, pollutographs, and total washoff loads may be output. The generation of a pollutograph for a particular constituent is accomplished by applying a potency factor for each size group to the ordinates of the appropriate loadograph, and summing for each size group. Thus

$$C_{i,n} = \sum_{j=1}^{5} L_{j,n} \cdot (P_{j,i})/(KQ_n) \qquad (12)$$

where $C_{i,n}$ is the concentration of pollutant i at time n, $L_{j,n}$ is the loadograph ordinate for group j at time n, $P_{j,i}$ is the potency factor in grams of constituent i per gram of sediment group j, Q_n is the discharge during interval n, and K is a conversion factor to produce units of mg/l. If street sweeping occurs during the period between events, the total removal of sediment for the basin as a whole and for each of the five subsets is output.

At the end of each month a summary table is output describing the total rainfall for the month; the runoff volume for each of the three cover types in inches per unit area; a basin composite runoff for the month, in inches; total sweeper removals, in kilograms; and total washoff loads for each sediment group and constituent being modeled, in kilograms. At the end of the run, the state variables are dumped for the moisture storages as well as for the surface loading of each reach. An updated branch-reach network file reflecting these new values for the state variables is also generated, and may be used to replace the original input file if so desired. The state variable dump and extra file may also be dumped for any interim date in the run. One additional file is output for water quality simulations. This file is a time line of surface loads. The total basin surface load for each of the five size groups and their sum is output along with the date (i.e., March 31 = day 90.0) at midnight of each day in the simulation. Whenever an event starts, the same data is output, and once again when the event ends. The end of event record also contains the total event rainfall. When sweeping occurs, the before and after conditions are also output.

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APPENDIX II

USER'S MANUAL FOR PROGRAM MANAGE

USERS MANUAL FOR DATA MANAGEMENT PROGRAM , "MANAGE"
NATIONAL URBAN RUNOFF PROGRAM

DOUGLAS NOEL
40 WRB
JUNE , 1980 VERSION

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I. DESCRIPTION OF DATA FILES

THE FIRST EXECUTION OF THE PROGRAM "MANAGE" FOR A PARTICULAR EVENT CREATES A FORMATTED DATA FILE WITH EITHER A USER-SPECIFIED TIME ARRAY OR A STANDARD TIME SCALE (ONE MINUTE TIME STEP) WITH BOTH RAINFALL AND DISCHARGE ARRAYS FROM TELEMETERED DATA. THESE FILES ARE NAMED BY THE FOLLOWING PROCEDURE :

THE FILENAME IS A SEVEN CHARACTER STRING. THE FIRST CHARACTER OF THE STRING IS AN ALPHA-NUMERIC WHICH IDENTIFIES THE BASIN WHICH THE DATA FILE WILL REPRESENT. THESE CHARACTERS ARE AS FOLLOWS :

A = MATTIS AVENUE NORTH
B = MATTIS AVENUE SOUTH
C = JAMES AND DANIEL
D = JOHN STREET SOUTH
E = JOHN STREET NORTH

THE SECOND AND THIRD CHARACTERS REPRESENT THE MONTH OF THE DATA , AND ARE REPRESENTED BY INTEGERS IN THE FOLLOWING FORMAT :

01 = JANUARY
10 = OCTOBER

THE FOURTH AND FIFTH CHARACTERS REPRESENT THE DAY OF THE MONTH , AND ARE REPRESENTED BY INTEGERS IN THE FOLLOWING FORMAT :

15 = FIFTEENTH DAY OF THE MONTH

THE SIXTH CHARACTER REPRESENTS THE YEAR OF THE EVENT , AND IS AN INTEGER AS FOLLOWS :

9 = 1979
0 = 1980
1 = 1981

THE LAST CHARACTER IS AN ALPHA-NUMERIC AND INDICATES THE EVENT NUMBER FOR THAT PARTICULAR DATE. ANYWHERE FROM ONE TO FOUR OR FIVE DISCRETE EVENTS MAY OCCUR IN A GIVEN DAY , AND EACH ONE , IN ORDER OF OCCURENCE , IS DESIGNATED BY A LETTER , STARTING WITH "A" FOR THE FIRST EVENT ON A GIVEN DATE , AND PROGRESSING IN ALPHABETICAL ORDER THROUGH THE LAST EVENT OF THAT DATE.

EACH FILE YOU CREATE MAY BE UP TO 241 RECORDS LONG. IF AN EVENT LASTS LONGER THAN FOUR HOURS , IT MAY BE INPUT AS ONE FILE IF THE INTERVAL IS USER SPECIFIED AT TWO OR MORE MINUTES , BUT THERE WILL BE PROBLEMS IF YOU ATTEMPT TO EXPAND THE FILE BY UTILIZING THE "TIME" MODE TO SHORTEN THE TIME STEP. THE BEST PROCEDURE IS THEN TO CREATE FILES ALLOWING FOR THE SHORTEST TIME STEP ANTICIPATED TO BE NEEDED. IF YOU NEED TO GENERATE TWO OR MORE DATA FILES FOR AN EVENT , START THE APPENDING FILE AT THE SAME TIME AS THE PREVIOUS FILE ENDED. THE HP PLOTTER OUTPUT OPTION WILL QUIZ YOU AS TO WHETHER OR NOT YOU INTEND TO APPEND YOUR PLOT DATA FILES IF IT SEES THAT THERE ARE 241 PLOTTING POINTS AND WILL , IF YOU INDICATE SO , SUPPRESS THE LAST RECORD SO AS TO AVOID A DUPLICATE RECORD IN EACH OF YOUR HP PLOTTER FILES. AFTER YOU HAVE PRINTED THE FIRST EVENT FILE IN HP PLOTTER FORMAT , YOU MAY THEN LOAD THE SECOND (OR THIRD) EVENT FILE AND ASK FOR HP PLOTTER PRINT. BY EXECUTING THE PRINTING OF THE DATA FROM THE SECOND DATA FILE IN THE SAME ORDER AS THE FIRST, YOU WILL BE APPENDING THE FIRST SET OF DATA FILES WITH THE SECOND. UPON EXITING THE PROGRAM , YOU MUST USE THE CYBER "PACK" COMMAND TO DELETE THE END OF DATA MARK THAT APPEARS AT THE END OF THE FIRST SEGMENT OF PRINTED DATA.

ALL DATA IN THE FILE IS STORED AS INTEGER DATA. THE FIRST RECORD CONTAINS EXPONENTS FOR EACH DATA ARRAY , IN BASE TEN. THE FIRST ARRAY , TIME , HAS A DEFAULT EXPONENT OF ZERO , AND THE VALUE STORED IN RECORD ONE IS THE NUMBER OF DATA RECORDS IN THE FILE. RECORDS TWO ONWARD CONTAIN THE EVENT DATA , WHICH IS FOLLOWED BY AN INTEGER , FOUR RECORDS AFTER THE END OF DATA. THIS INTEGER REPRESENTS THE NUMBER OF RECORDS OF COMMENTS IN THE FILE , WHICH MAY NOT EXCEED TWO HUNDRED. THE PROGRAM ASKS YOU FOR THE DATE AND YOUR INITIALS AS YOU START , AND WILL PRINT THESE IN THE COMMENT BLOCK ALONG WITH THE ARRAY NUMBERS OF ANY FILES YOU UPDATE AS YOU EXIT THE PROGRAM.

AN EXAMPLE DATA FILE IS GIVEN IN SECTION VIII. FOR MATTIS AVENUE NORTH BASIN , FOR THE EVENT OF NOVEMBER 22,1979 (FILENAME=A11229A) , BEGINNING AT 2:16 AM , AND ENDING AT 2:56 AM , AT FIVE MINUTE INTERVALS. THERE ARE 6 COMMENT CARDS.

THE FOLLOWING TABLE GIVES THE RANGE OF VALUES WHICH CURRENTLY ARE ACCEPTABLE FOR THE ARRAYS AS THEY EXIST :

ITEM	FROM	TO	COMMENTS
TIME	0001	2400	MINUTES
RAINFALL	0.01	9.99	INCHES
DISCHARGE	0.1	99.9	CFS
TOTAL SUSPENDED SOLIDS	1.0	9999.	MGL
TOTAL DISSOLVED SOLIDS	1.0	999.	MGL
SULFATE	10.0	99.0	MGL
CHLORIDE	0.1	999.9	MGL
AMMONIA	0.1	9.9	MGL
DISSOLVED AMMONIA			
NITRITE	0.1	9.9	MGL
DISSOLVED NITRITE			
KJELDAHL-NITROGEN	0.1	9.9	MGL
DISSOLVED KJELDAHL-NITROGEN			
PHOSPHORUS	0.01	9.9	MGL
DISSOLVED PHOSPHORUS			
ORGANIC CARBON	1.0	99.0	MGL
DISSOLVED ORGANIC CARBON			
CHEMICAL OXYGEN DEMAND	1.0	999.	MGL
LEAD	0.1	9.9	MGL
DISSOLVED LEAD			
COPPER	.005	.999	MGL
DISSOLVED COPPER			
IRON	0.01	99.99	MGL
DISSOLVED IRON			
ZINC	0.01	9.99	MGL
DISSOLVED ZINC	0.01	0.99	MGL
CHROMIUM	.005	.099	MGL
DISSOLVED CHROMIUM			
CADMIUM	.005	.099	MGL
DISSOLVED CADMIUM			
MANGANESE	0.01	9.99	MGL
DISSOLVED MANGANESE			
NICKEL	0.05	0.99	MGL
DISSOLVED NICKEL			
MERCURY			MICRO-GRAMS/LITER
PH	0.1	9.9	
SPECIFIC CONDUCTANCE	10.	999.	MICRO MHOS

II. PROGRAM STRUCTURE

THE PROGRAM IS STRUCTURED AS SIX BASIC OPERATIONAL MODUALS , OR "MODES". THESE MODES ARE :

INIT - CREATE A NEW FILE TO USER SPECIFICATIONS
TELE - CREATE THE STANDARD FILE FROM TELEMETERED DATA
TIME - UPDATE TIME RANGE AND/OR STEP
DATA - ENTER OR UPDATE DATA ARRAYS
PRNT - LINE PRINTER OR HP PLOTTER OUTPUT FILE(S)
EXIT - TERMINATE WORK ON FILE

THE TERM "STANDARD FILE" , AS USED ABOVE , REFERS TO ONE MINUTE TIME STEP OF THE DATA , WHICH IS THE TELEMERED DATA AND ILLUDAS INTERVAL.

THE INTENDED USE AND OPERATIONS UNDER EACH OF THESE MODES IS DISCUSSED IN THE FOLLOWING SECTIONS.

NOTE : IN THE FOLLOWING SECTIONS , BOTH THE PROGRAM PROMPTS AND THE USER RESPONSE WILL BE DISCUSSED. THE FORMAT OF THESE ACTIONS WILL FOLLOW THIS FORMAT :

> ALL PROGRAM GENERATED MESSAGES WILL BE PRINTED EXACTLY AS THEY WILL APPEAR ON YOUR TERMINAL, EXCEPT THAT THEY WILL BE ENCLOSED IN QUOTATION MARKS.
>
> WHEN A USER RESPONSE IS EXPECTED , THE RESPONSE AREA WILL BE ENCLOSED BY A PAIR OF ASTERIKS ON EITHER SIDE.

III. CREATING A NEW FILE

A) OPERATING MODE "INIT"

AFTER BEING ASKED FOR YOUR INITIALS AND THE DATE. THE FOLLOWING MESSAGE WILL APPEAR :

```
"IS THIS BASIN JAMES AND DANIEL ?
 ?"**  **
```

A **YES** REPONSE WILL CHANGE THE DISCARGE EXPONENT FROM TENTHS TO HUNDREDTHS. THIS QUESTTION IS NOTHING MORE THAN A DUMMY HOWEVER IF YOU ARE NOT CREATING A NEW FILE IN EITHER "INIT" OR "TELE". THE NEXT PROMPT WILL BE :

```
"THE FOLLOWING LISTS THE OPERATION MODES

    INIT     TELE     TIME     DATA     PRNT

ENTER THE MODE KEYWORD OF THE NEXT TASK
?" **    **
```

IF YOU WISH TO CREATE A DATA FILE TO YOUR OWN SPECIFICATIONS , YOU ANSWER **INIT** . IF YOU ARE CREATING A DATA FILE FROM TELEMETERED DATA , YOU ANSWER **TELE** . THE LATTER CASE WILL BE DISCUSSED IN SECTION III.B. IF YOU ARE WORKING ON A FILE WHICH HAS ALREADY BEEN CREATED , YOU ENTER THE APPROPRIATE KEYWORD AND CONTINUE AS PER THE INSTRUCTIONS IN SECTIONS IV.A. , IV.B. , OR V.A. AND V.B.

IN ALL ENSUING RETURNS TO THE OPERATION MODE CHOICE , THE FOLLOWING MESSAGE WILL APPEAR :

```
"THE FOLLOWING LISTS THE OPERATION MODES

    TIME     DATA     PRNT     EXIT

ENTER THE MODE KEYWORD OF THE NEXT TASK
?" **    **
```

THE FILE CREATION OPTIONS ARE GONE BECAUSE ONCE YOU HAVE EXECUTED ONE TASK , YOU HAVE A WORKING FILE , REGARDLESS OF WHETHER YOU HAD ONE TO BEGIN WITH OR NOT.

AFTER ISSUING THE KEYWORD **INIT** , THE PROGRAM WILL RESPOND :

```
"ENTER THE START TIME OF THE DATA
?"**    **
```

YOU NOW ENTER THE MILITARY TIME OF THE BEGINNING OF THE EVENT. FOR EXAMPLE :

0216 = 2:16 AM
1300 = 1:00 PM

THE PROGRAM WILL RESPOND :

```
"ENTER THE FINISH TIME OF THE DATA
?"**    **
```

YOU NOW ENTER THE MILITARY TIME AT WHICH THE EVENT ENDED.THE PROGRAM WILL NOW RESPOND WITH :

```
"ENTER THE TIME STEP IN MINUTES
?"**    **
```

YOU NOW ENTER A FLOATING POINT NUMBER WHICH IS THE INTERVAL AT WHICH YOU WANT YOUR FILE TO BE CREATED. THIS NUMBER MUST BE WHOLE MINUTES.

FOR EXAMPLE :

1. = ONE MINUTE
5. = FIVE MINUTES
2.5 = TWO AND A HALF MINUTES AND IS NOT ALLOWED

THE PROGRAM WILL GENERATE THE TIME ARRAY , THEN IT WILL ZERO ALL OF THE CORRESPONDING DATA ARRAYS , AND FINALLY WILL ASSIGN THE DATA ARRAY EXPONENTS , WHICH , AS PREVIOUSLY EXPLAINED , CONTAIN THE NUMBER OF DATA INTERVALS AS AN EXPONENT FOR THE TIME ARRAY.

YOU WILL NOW BE TRANSFERRED BACK TO OPERATION MODE CHOICE STATUS.

NOTE : FROM HERE ON OUT , WHENEVER YOU ARE ASKED FOR A START TIME AND/OR FINISH TIME AND AND/OR A TIME STEP , THEY MUST BE ENTERED SUCH THAT BY STARTING AT YOUR SPECIFIED START TIME , AND INCREMENTING BY EITHER YOUR SPECIFIED TIME STEP , OR AN EXISTING TIME STEP , THE FINISH TIME MAY BE EXACTLY REACHED. THE SAME IS TRUE LATER ON WHEN YOU ARE IN "DATA" MODE , IF YOU NEED TO START DATA OR UPDATE DATA AT SOME POINT IN THE EXISTING TIME RANGE , THE TIME YOU ENTER MUST EXIST IN THE ARRAY OR BE ATTAINABLE BY EITHER INCREMENTING OR DECREMENTING BY THE EXISTING TIME STEP.

FOR EXAMPLE :

IF YOUR START TIME IS 0216
FINISH TIME IS 0256
AND TIME STEP IS 5.0

0231.0201. AND 0316 CAN ALL BE ACCEPTABLE TIMES UNDER DIFFERENT OPERATION MODES.

0222.0240.0300. AND 0200 WOULD BE UNACCEPTABLE BECAUSE THEY CAN NOT BE REACHED FROM EITHER 0216 OR 0256 AT FIVE MINUTE INTERVALS.

B) OPERATING MODE "TELE"

IF YOU CHOOSE **TELE** AS YOUR OPERATING MODE . THE PROGRAM WILL RESPOND :

```
"PROJECT BASINS ARE :

     NORTH MATTIS                SOUTH MATTIS                JAMES AND DANIEL
               SOUTH JOHN                      NORTH JOHN

ENTER BASIN TO BE GENERATED
?" **                        **
```

WHEN YOU ENTER THE CURRENT BASIN NAME . THE PROGRAM WILL REPOND :

```
"ENTER BUBLER NUMBER FOR THIS SITE AND EVENT
?"**  **
```

YOU NOW ENTER THE BUBBLER NUMBER SO THAT THE PROGRAM MAY MAKE THE NECESSARY ZERO ADJUSTMENT . IF THE BASIN YOU CHOSE WAS EITHER OF THE TWO JOHN STREET BASINS . YOU WOULD HAVE BEEN PROMPTED WITH :

```
"ENTER UPSTREAM BUBBLER NUMBER FOR THIS SITE AND EVENT
?"**  **
```

YOU NOW ENTER THE APPROPRIATE BUBBLER NUMBER . AND ARE PROMPTED :

```
"ENTER DOWNSTREAM BUBBLER NUMBER FOR THIS SITE AND EVENT
?"**  **
```

YOU NOW ENTER THE OTHER BUBBLER NUMBER FOR THESE SITES. THE PROGRAM PREFERS TO GENERATE DISCHARGE FROM THE UPSTREAM BUBBLER AT THESE SITES BUT ALLOWS THE DOWNSTREAM STAGE TO BE USED IF THE UPSTREAM VALUE IS IN DOUBT. IF YOU ENTER THE SAME BUBBLER NUMBER FOR BOTH . THE FOLLOWING ERROR MESSAGE APPEARS :

```
"UPSTREAM=DOWNSTREAM . RE-ENTER BUBBLERS"
```

AT WHICH POINT YOU ARE QUIZZED ON THE BUBBLER NUMBERS AGAIN.

NEXT . YOU ARE ASKED THE FOLLOWING SERIES OF QUESTIONS ABOUT THE FILE YOU ARE CREATING :

```
"ENTER DESIRED TIME STEP . IN MINUTES
?"**   **
"ENTER NUMBER OF RECORDS IN TELEMETERED FILE
?"**   **
"ENTER STARTING TIME FOR DESIRED FILE
?"**    **
"ENTER FINISH TIME FOR DESIRED FILE
?"**    **
```

IF THE START TIME THAT YOU ENTER DOES NOT EXIST . THE FOLLOWING MESSAGE IS PROMPTED :

```
"INDICATED START TIME DOES NOT FIT EVENT"
```

YOU WOULD NOW BE TRANSFERED BACK TO THE PROMPT FOR START AND FINISH TIMES. ONCE YOUR START TIME IS COMPATIBLE WITH THE FILE . THE PROGRAM ALLOWS UP TO 241 ENTRIES IN THE TIME ARRAY AT THE USER SPECIFIED TIME STEP. IF YOUR FINISH TIME OCCURS BEFORE THAT LIMIT . YOU ARE SHIFTED BACK TO OPERATION MODE CHOICE . IF NOT . THE FOLLOWING WILL APPEAR :

```
"INDICATED FINISH TIME DOES NOT FIT EVENT
 SELECTED EVENT ENDS AT (TTTT)
 DO YOU WISH TO CHANGE TIME STEP OR START/FINISH TIMES ?
 ?"**    **
```

THE VALUE ECHOED AS TTTT WILL BE THE FINISH TIME AS COMPUTED BY THE START TIME PLUS TWO HUNDRED AND FORTY TIMES THE TIME STEP. A **YES** RESPONSE WILL SEND YOU BACK TO THE QUERIES ABOUT TIME STEP AND START-FINISH TIMES. A **NO** RESPONSE WILL PROMPT :

```
"EVENT FILE WILL END AT (TTTT)"
```

YOU WILL NOW BE TRANSFERRED BACK TO OPERATION MODE CHOICE. IF THE PARTICULAR EVENT SHOULD REQUIRE MORE THAN 241 ENTRIES. A SECOND FILE MAY BE GENERATED STARTING AT TIME TTTT.

IV. DATA INPUT , UPDATE , AND MANIPULATION

A) OPERATING MODE "TIME"

THE CHOICE OF **TIME** AS AN OPERATING MODE ALLOWS YOU TO CHANGE THE RANGE OF YOUR DATA SET , FROM START TO END , AND/OR THE TIME STEP , WHILE PRESERVING ALL EXISTING DATA , IF YOU ARE CAREFUL. THE RAINFALL DATA CAN NOT BE DISTRIBUTED IF YOU CHOOSE TO SHORTEN THE TIME STEP , BUT YOU CAN DO THIS MANUALLY FROM THE "DATA" MODE. THE FIRST RESPONSE AFTER SELECTION OF THIS MODE IS :

```
"THE EVENT CURRENTLY BEGINS AT        AND ENDS AT
DO YOU WISH TO CHANGE THIS RANGE ?
?" **  **
```

A **NO** ANSWER WILL TRANSFER YOU TO THE TIME STEP QUESTION DISCUSSED LATER IN THIS SECTION. A **YES** ANSWER WILL PROMPT THE FOLLOWING :

```
"THE CURRENT INTERVAL OF THE DATA IS      MINUTES
DO YOU WISH TO CHANGE THE START TIME ?
?" **  **
```

IF YOU ANSWER **NO** , YOU WILL BE TRANSFERRED TO THE END TIME QUESTION. A **YES** ANSWER WILL RESPOND WITH :

```
"ENTER THE TIME AT WHICH THE DATA SHOULD BEGIN
?" **     **
```

YOU ANSWER WITH THE MILITARY TIME AT WHICH YOU WANT THE DATA TO BEGIN. REMEMBER IT MUST BE ACCESSABLE FROM THE GIVEN START TIME BY THE GIVEN TIME STEP , ALTHOUGH IN THIS INSTANCE , YOU MAY MAKE THE FILE BEGIN EARLIER OR LATER THAN THE EXISTING FILE. IF YOU CHOOSE A LATER START TIME , ALL DATA PRIOR TO THE NEW START TIME WILL BE LOST , WITH THE EXCEPTION OF RAINFALL , WHICH WILL BE ACCUMULATED TO YOUR NEW START TIME. THE NEXT PROMPT WILL BE :

```
"DO YOU WISH TO CHANGE THE END TIME ?
?" **  **
```

A **NO** ANSWER WILL CAUSE THE PROGRAM TO PRINT BOTH THE FIRST TWO AND LAST TWO ELEMENTS OF THE TIME ARRAY AS FOLLOWS :

```
"    T(  1) =
     T(  2) =
     T(N-1) =
     T( N ) =      "
```

AT THIS TIME YOU WILL BE TRANSFERED BACK TO OPERATION MODE CHOICE STATUS.

A **YES** ANSWER CAUSES THE FOLLOWING PROMPT :

```
"ENTER THE TIME AT WHICH THE DATA SHOULD END
?" **     **
```

YOU RESPOND BY ENTERING THE MILITARY TIME AT WHICH THE FILE SHOULD NOW END. IF IT IS LATER THAN THE CURRENT END TIME , ALL THE DATA FILES WILL BE EXTENDED WITH ZERO DATA THROUGH THE END OF YOUR NEW TIME ARRAY. IF IT IS EARLIER , ALL DATA AFTER YOUR NEW END TIME IS ZEROED , WITH THE EXCEPTION OF RAINFALL , WHICH WILL BE ACCUMULATED BACK TO YOUR NEW END TIME.

THE FIRST AND LAST TWO ELEMENTS OF YOUR TIME ARRAY WILL NOW BE PRINTED , AS SHOWN ABOVE , AND YOU WILL BE TRANSFERRED TO OPERATION MODE CHOICE STATUS.

IF YOU DID NOT WANT TO ALTER EITHER THE START TIME OR FINISH TIME OF THE DATA FILE , A **NO** ANSWER TO THE FIRST QUESTION IN THIS MODE , THE FOLLOWING PROMPT WILL OCCUR :

```
"THE CURRENT INTERVAL OF THE DATA IS     MINUTES
DO YOU WISH TO CHANGE THIS RANGE ?
?" **  **
```

A **NO** ANSWER WILL TRANSFER YOU BACK TO OPERATION MODE CHOICE STATUS. A **YES** WILL PROMPT THE FOLLOWING :

```
"ENTER THE TIME STEP IN MINUTES
?" **     **
```

YOU ANSWER BY ENTERING A FLOATING POINT NUMBER (WHOLE) WHICH MUST BE AN INTEGER MULTIPLE OF THE EXISTING INTERVAL IF YOU WISH TO LENGTHEN THE TIME STEP (AS IN GOING FROM 5 MINUTES TO 10 MINUTES) OR, IF YOU WISH TO SHORTEN THE TIME STEP , THE CURRENT INTERVAL MUST BE AN INTEGER MULTIPLE OF YOUR NEW TIME STEP (AS IN GOING FROM 5 MINUTES TO 1 , OR 10 MINUTES TO 5 , 2 , OR 1).

WHEN SHORTENING THE INTERVAL , BLANK RECORDS ARE INSERTED AT THE APPROPRIATE FREQUENCY. IF RAINFALL DATA EXISTS , IT IS UP TO YOU TO MAKE ANY NECCESSARY CHANGES FROM "DATA" MODE.

WHEN LENGTHENING THE INTERVAL , RECORDS (AND ANY EXISTING DATA AT THE ODD INTERVALS) ARE DELETED. RAINFALL IS ACCUMULATED FORWARD IN TIME TO THE NEXT RECORD WHICH IS TO BE RETAINED.

THE PROGRAM NOW TRANSFERS BACK TO OPERATION MODE CHOICE STATUS.

B) OPERATING MODE "DATA"

IF **DATA** WAS CHOSEN AS YOUR OPERATION MODE , THE PROGRAM WILL RESPOND :

```
"IS THE PROCEDURE DATA INPUT TO A TELE-CREATED FILE ?
?"**     **
```

IF YOU ARE INPUTTING DATA TO A NEWLY CREATED FILE FROM "TELE" , YOU RESPOND **YES** , AND THE PROGRAM WILL CONTINUE AS DISCUSSED AT THE END OF THIS SECTION. IF NOT , YOU RESPOND **NO** , WHICH WILL PROMPT THE FOLLOWING :

```
"THE FOLLOWING IS A LIST OF ACCEPTABLE KEYWORDS :

     RAIN      FLOW      TSS       TDS       SO4       CL2       NH4       DNH4      NO3
     DNO3      K-N       DK-N      P         DP        ORC       DORC      COD       PB
     DPB       CU        DCU       FE        DFE       ZN        DZN       CR        DCR
     CD        DCD       MN        DMN       NI        DNI       HG        PH        SC

ENTER THE NAME OF THE DATA SET ON WHICH YOU INTEND TO WORK
?"**                            **
```

AT THIS POINT YOU ARE EXPECTED TO ENTER THE KEYWORD OF THE DATA SET YOU NEED TO WORK ON "EXACTLY" AS IT APPEARS ABOVE. THESE KEYWORDS ARE IN THE SAME ORDER AS LISTED IN THE CONSTITUENT LIST DISCUSSED EARLIER. IF YOU MIS-SPELL THE KEYWORD , THE FOLLOWING MESSAGE WILL APPEAR :

```
"KEYWORD MIS-SPELLED OR NOT IN LIST : TRY AGAIN
ENTER THE NAME OF THE DATA SET ON WHICH YOU INTEND TO WORK
?" **                           **
```

IF YOU MIS-SPELL IT A SECOND TIME , THE ENTIRE LISTING IS GOING TO BE REPEATED FOR YOU. THE PROGRAM WILL SCAN THE ARRAY NOW TO DETERMINE WHETHER OR NOT DATA HAS BEEN INPUT TO THIS DATA SET BEFORE. IF NOT , THE PROMPT :

```
"NO NON-ZERO DATA EXISTS FOR (DATA SET KEYWORD)"
```

WILL APPEAR , AND YOU WILL BE ASKED FOR A START TIME , AS EXPLAINED AT THE BOTTOM OF THIS PAGE.

IF DATA DOES EXIST , THE FOLLOWING WILL APPEAR :

```
"DATA EXISTS AND MAY BE OVERWRITTEN FOR (DATA SET KEYWORD)
WAS THIS DATA SET INPUT AT THE WRONG START TIME ?
?" **  **
```

A **YES** ANSWER ALLOWS YOU TO MOVE AN ENTIRE ARRAY BACKWARD OR FORWARD IN TIME , ASSUMING THAT YOU STARTED YOUR DATA INPUT AT THE WRONG TIME , AND CARRIED THE ERROR THROUGHOUT THE DATA SET. THIS FEATURE IS DISCUSSED FURTHER NEAR THE END OF THIS SECTION.

BOTH A NEW FILE AND A **NO** TO THE LAST QUESTION WILL PROMPT :

```
"ENTER THE START TIME OF THE DATA
?" **    **
```

IF YOU ARE INPUTTING DATA FOR THE FIRST TIME , ENTER THE TIME OF YOUR FIRST OBSERVATION , NOT NECCESSARILY BEING THE SAME AS THE START TIME OF THE FILE. IF YOU ARE UPDATING ONE DATA POINT , ENTER THE TIME OF THIS POINT , IF YOU ARE UPDATING A CONTINUOUS STRING OF DATA POINTS , ENTER THE TIME OF THE FIRST DATA TO BE UPDATED. REMEMBER THAT THESE TIMES MUST BE ACCESSABLE BY THE TIME STEP OF THE EXISTING DATA FILE BY MEANS OF THE EXISTING DATA START TIME.

THE PROGRAM WILL NEXT PROMPT :

```
"ENTER THE FINISH TIME OF THE DATA
?" **    **
```

YOU NOW ENTER THE TIME AT WHICH YOUR LAST OBSERVATION TOOK PLACE , IF YOU ARE INPUTTING NEW DATA. IF YOU ARE UPDATING ONE POINT , ENTER THE SAME TIME AS YOU DID FOR THE START TIME. IF YOU ARE UPDATING A STRING OF POINTS , ENTER THE LAST TIME IN THE STRING.

THE NEXT PROMPT IS :

```
"ENTER THE TIME STEP IN MINUTES
?" **    **
```

THIS IS TO BE A FLOATING POINT NUMBER , AT LEAST AS LARGE AS THE TIME STEP OF THE EXISTING FILE. IF YOU HAVE A FIVE MINUTE FILE WITH TEN MINUTE OBSERVATIONS , THERE IS NO POINT IN MAKING ZERO ENTRIES , SO RESPOND WITH **10** . THE SAME CONSTRAINTS AS BEFORE EXIST IN THAT THE TIME STEP MUST BE AN INTEGER MULTIPLE OF THE EXISTING TIME STEP. THIS IS TRUE ALSO IF YOU ARE UPDATING A STRING OF DATA POINTS. IF YOU ARE UPDATING ONE POINT , ANY NON-ZERO POSITIVE NUMBER WILL DO.

ONCE THE ABOVE THREE PARAMETERS HAVE BEEN DECLARED , THE PROGRAM WILL RESPOND :

```
"TIME =        , DATA =
ENTER NEW DATA
?" **    **
```

THIS MESSAGE WILL PRINT THE TIME AND CURRENT VALUE OF YOUR DATA FOR THAT TIME FOR EVERY POINT ACCESSED BY THE PARAMETERS YOU HAVE CHOSEN. THE PROGRAM ACCEPTS A FLOATING POINT NUMBER EXACTLY AS THE DATA ON THE LAB SHEETS APPEARS. THE PROGRAM WILL INTERNALLY CONVERT THIS NUMBER TO AN INTEGER VALUE FOR STORAGE. IF YOU ARE UPDATING AN ARRAY AND DO NOT WISH TO CHANGE THE EXISTING VALUE , OR IF YOU DONT WANT TO ENTER ZEROES , ANY NEGATIVE INTEGER WILL CAUSE THE PROGRAM TO SKIP TO THE NEXT DATA POINT WITHOUT CHANGING THE CURRENT ENTRY. IN THE EVENT THAT "TRACE" AMMOUNTS OCCUR ON THE LAB SHEETS , RESPONDING WITH **-999** WILL CAUSE THE PROGRAM TO DENOTE THE FACT THAT A TRACE AMMOUNT EXISTS FOR THIS CONSTITUENT FOR THE CURRENT INTERVAL , AND WILL RESPOND :

```
"TRACE AMMOUNT WILL BE REPRESENTED BY : C "
```

IN THIS CASE "C" INDICATES TRACE AMMOUNTS FOR TSS , A DIFFERENT ALPHA-NUMERIC CHARACTER INDICATES EACH CONSTITUENT , WITH A DOUBLE LETTER INDICATING A TRACE AMMOUNT OF THE DISSOLVED PORTION OF A PARTICULAR CONSTITUENT.

WHEN YOU HAVE ENTERED THE LAST DATA IN YOUR SPECIFIED RANGE , THE PROGRAM WILL RESPOND :

```
"DO YOU NEED TO WORK ELSEWHERE ON THIS FILE ?
?" **    **
```

A **YES** ANSWER ALLOWS YOU TO SPECIFY A NEW START , FINISH , AND TIME STEP IF THERE IS A SECOND STRING OF DATA TO BE UPDATED IN THE FILE OR IF THE OBSERVATION INTERVAL CHANGES IN THE FILE.

A **NO** ANSWER RESPONDS WITH :

```
"DO YOU NEED TO WORK ON OTHER DATA SETS ?
?" **  **
```

A **YES** ANSWER WILL RESPOND BY ASKING IF YOU NEED THE KEYWORDS REPEATED , AT WHICH POINT YOU WILL GET A LISTING IF SO DESIRED , AND THEN YOU WILL BE ASKED FOR A KEYWORD , AND REPEAT THE ABOVE PROCEDURE. A **NO** ANSWER WILL RESPOND :

```
"DO YOU WISH TO MAKE COMMENTS ON THE DATA ?
?" **  **
```

A **NO** ANSWER TRANSFERS THE PROGRAM TO OPERATION MODE CHOICE STATUS. A **YES** ANSWER RESPONDS :

```
"ENTER JUST ONE COMMENT AT A TIME , USING AS MANY LINES AS NEEDED
SEPARATE EACH COMMENT BY A LINE CONTAINING ONLY THE WORD SPACE
END YOUR COMMENTS WITH A LINE CONTAING ONLY THE WORD END
?" **             **
```

THE SET OF QUESTION MARK PROMPTS WILL CONTINUE UNTIL THE WORD "END" IS ENCOUNTERED AS THE ONLY ENTRY ON THE LINE. EACH COMMENT MAY BE UP TO SEVENTY-TWO CHARACTERS LONG. UP TO 200 LINES OF COMMENTS ARE ALLOWED. YOU MAY WANT TO COMMENT ON WHEN DATA ARRIVED FROM THE LAB , OR SAMPLER MALFUNCTIONS , ETC . IT IS NOT NECESSARY TO INDICATE WHICH FILES YOU WORKED ON AND WHEN . THE INITIALS AND DATE YOU ENTERED AT THE START OF THE PROGRAM WILL BE USED AS COMMENTS IF YOU MADE ANY CHANGES TO THE DATA SETS , ALONG WITH THE INTERNAL ARRAY NUMBER OF THE DATA YOU ALTERED. WHEN YOU HAVE SIGNALED THE END OF YOUR COMMENTS , THE PROGRAM WILL SHIFT BACK TO OPERATION MODE CHOICE STATUS.

IF YOU ANSWERED **YES** TO THE PROMPT :

```
"WAS THIS DATA SET INPUT AT THE WRONG START TIME ?
?" **  **
```

THE PROGRAM WILL RESPOND :

```
"DATA CURRENTLY BEGINS AT
ENTER THE TIME AT WHICH THE DATA SHOULD BEGIN
?" **     **
```

YOU NOW ENTER THE TIME AT WHICH THIS ARRAY SHOULD HAVE HAD ITS FIRST DATA POINT , AND THE PROGRAM WILL SHIFT THE ENTIRE ARRAY TO THIS START TIME BY AN INTERVAL EQUAL TO THE DIFFERENCE BETWEEN THE CURRENT START TIME AND THE ONE YOU HAVE JUST SPECIFIED. THE PROGRAM WILL THEN ECHO THE ENTIRE ARRAY , ALONG WITH THE TIME ARRAY , IN THE FOLLOWING FORMAT :

```
"TIME =          , DATA =
 TIME =          , DATA =
              :
              :
 TIME =          , DATA =          "
```

IT WILL THEN ASK IF YOU NEED TO WORK ON OTHER DATA SETS AND CONTINUE AS ABOVE.

IN THE CASE OF DATA INPUT FOR NEWLY-CREATED TELEMETERED DATA FILES YOU WILL FIRST HAVE THE KEYWORDS REPEATED , AND UPON ENTERING THE NAME OF THE FIRST CONSTITUENT TO BE WORKED ON , THE PROGRAM AUTOMATICALLY

SCANS THE CONSTITUENT ARRAYS AND ASKS FOR DATA ONLY AT TIMES WHEN THE SAMPLERS DREW WATER. THE PROMPT WILL APPEAR AS FOLLOWS :

```
"ENTER NH4  CONCENTRATION FOR TIME = 0800
?"**      **
```

IN THE ABOVE PROMPT , NH4 AND 0800 ARE FOR THE PURPOSE OF EXAMPLE ONLY. THE USER RESPONSE MAY BE TO ENTER LAB DATA, ZEROES (WHEN A PARTICULAR SAMPLE WAS NOT USED TO DETERMINE A CONCENTRATION FOR THIS CONSTITUENT) , OR THE TRACE AMMOUNT RESPONSE , AS DISCUSSED ABOVE. THE PROGRAM WILL ASK WHETHER OR NOT YOU WISH TO INPUT DATA TO OTHER ARRAYS AND CONTINUE AS ABOVE. THIS SUBROUTINE IS FOR INPUT ONLY, NOT UPDATE. IF THE PROGRAM FINDS NO EMPTY SAMPLE TIMES IN THE CONSTITUENT ARRAY YOU SPECIFY, IT WILL IMMEDIATELY ASK IF YOU WANT TO WORK ON OTHER DATA SETS.

V. DATA OUTPUT (OPERATING MODE "PRNT")

A) LINE PRINTER OUTPUT

WHEN YOU SELECT MODE **PRNT** , THE PROGRAM WILL RESPOND :

```
"IS PRINT TO BE IN HP PLOTTER FORMAT ?
?" **  **
```

A **YES** ANSWER ENABLES DATA SETS TO BE PRINTED OUT TO FILES IN THE FORMAT REQUIRED FOR USE WITH THE PROGRAM TO PLOT NURP DATA , WHICH IS DISCUSSED IN THE NEXT SECTION.

A **NO** ANSWER WILL CAUSE THE PROGRAM TO INSPECT THE FILE AND DETERMINE HOW MANY COMMENT RECORDS EXIST. THE PROGRAM THEN PRINTS THE DATA IN ITS INTEGER FORMAT WITH THE ARRAYS APROPRIATELY LABELED , FOLLOWED BY A RECORD WHICH CONTAINS THE EXPONENTS OF THE DATA SETS. THE PROGRAM THEN SKIPS THREE RECORDS AND WRITES THE NUMBER OF COMMENT RECORDS ON THE OUTPUT. YOU ARE THEN PROMPTED :

```
"(#) COMMENT RECORDS EXIST
DO YOU WANT COMMENTS PRINTED ?
?" **  **
```

A **YES** ANSWER PRINTS THE COMMENTS AT THE END OF THE DATA. AT THIS POINT , EITHER ANSWER CAUSES THE FOLLOWING MESSAGE:

```
"THE PRINTED DATA IS IN FILE OUT
YOU MUST PRINT TO SWS WHEN YOU EXIT"
```

THE PROGRAM NOW RETURNS TO OPERATION MODE CHOICE STATUS. THE COMMAND THAT WILL PRINT THE FILE NAMED "OUT" IS DISCUSSED IN SECTION VII.B. AN EXAMPLE OF THIS OUTPUT IS PRESENTED IN SECTION IX.

B. OUTPUT FOR HP PLOTTER

IF YOU ANSWERED **YES** TO THE QUESTION :

```
"IS PRINT TO BE IN HP PLOTTER FORMAT ?
?" **  **
```

THE FOLLOWING RESPONSE WILL APPEAR :

```
"THE CURRENT INTERVAL OF THE DATA IS      MINUTES
 ENTER THE TIME STEP IN MINUTES
?"**     **
"THE EVENT CURRENTLY BEGINS AT       AND ENDS AT      .
 ENTER THE START TIME OF THE DATA
?"**      **
"ENTER THE FINISH TIME OF THE DATA
?"**      **
```

YOU RESPOND TO EACH OF THESE PROMPTS BY ENTERING THE THREE PARAMETERS THAT WILL PRODUCE THE PLOTTING DATA YOU NEED. SUBJECT TO THE PREVIOUSLY DISCUSSED CONSTRAINTS ON TIME STEP AND THE REQUIREMENT THAT BOTH THE START AND FINISH TIME THAT YOU SPECIFY MUST EXIST IN THE DATA FILE. IF YOUR FILE IS PART OF AN EVENT ENCOMPASSSING MORE THAN ONE DATA FILE , YOU MAY ASK FOR THE ENTIRE 241 RECORDS TO BE OUTPUT , WHICH WILL PROMPT :

```
"IS THE EVENT CONTINUED ON ANOTHER FILE ?
?"**    **
"ARE YOU GOING TO PLOT FROM THE SECOND FILE ?
?"**    **
```

A **NO** REPONSE TO THE FIRST QUESTION WILL BYPASS THE SECOND AND SKIP DIRECTLY TO THE FILE INFORMATION QUESTIONS DISCUSSED BELOW. BY ANSWERING **YES** , YOU ARE ALLOWED TO EITHER SUPPRESS THE 241ST RECORD BY ANSWERING **YES** A SECOND TIME , OR PLOT THE LAST VALUE IF YOU DONT WISH TO PLOT THE TRAILING DATA (E.G. THE 24 SAMPLES MAY HAVE BEEN TAKEN IN THE FIRST FOUR HOURS , IN WHICH CASE NOTHING BUT DISCHARGE AND RAIN DATA EXIST IN THE SUCCEEDING FILES).

YOU ARE NOW READY TO TELL THE PROGRAM WHICH CONSTITUENT FILES YOU WANT TO OUTPUT FOR PLOTTING. THE KEYWORD SELECTION PROCESS IS IDENTICAL TO THAT FOR DATA INPUT/UPDATE. THE PROGRAM WILL GENERATE ONE FILE PER REQUESTED CONSTITUENT UNTIL YOU EITHER ANSWER **NO** TO THE FOLLOWING QUESTION OR UNTIL THE TWENTY ALLOWABLE OUTPUT FILES ARE FILLED. THE PROGRAM PROMPTS FOR ADDITIONAL DATA OUTPUT WITH :

```
"DO YOU WISH TO PRINT OTHER FILES ?
?"**    **
```

ONCE YOU HAVE TERMINATED THE DATA OUTPUT , THE PROGRAM WILL ECHO THE CONSTITUENTS AND THEIR DEFAULT FILE NAMES AS FOLLOWS :

```
"(FIRST      DATA SET NAME) WILL BE PRINTED TO FILE 011
 (SECOND     DATA SET NAME) WILL BE PRINTED TO FILE 012
                          :
                          :
 (TWENTIETH DATA SET NAME) WILL BE PRINTED TO FILE 030"
```

THE FILES MAY BE RENAMED AND SAVED IF SO DESIRED , OR THEY MAY BE PLOTTED UNDER THE ABOVE DEFAULT NAMES. IF YOU ARE APPENDING HP PLOTTER OUTPUT FILES , DO NOT EXECUTE THE "RWF" COMMAND BEFORE RELOADING THE MAIN PROGRAM. ALSO REMEMBER THAT IN ORDER TO APPEND THE CORRECT DATA TO

EXISTING FILES . THE CONSTITUENTS MUST BE PRINTED IN THE SAME ORDER THE SECOND TIME THROUGH AS THEY WERE THE FIRST TIME. BEFORE PLOTTING OR SAVING THESE APPENDED FILES . THEY MUST BE "PACKED" BY THE PROCEDURE OUTLINED IN SECTION VII.B.

VI. PROGRAM TERMINATION

A) OPERATING MODE "EXIT"

NORMAL TERMINATION OF THIS PROGRAM OCCURS THROUGH THE SELECTION OF **EXIT** AS AN OPERATING MODE. IF . WHEN YOU CHOOSE **EXIT** . THE ONLY OPERATIONS YOU HAVE EXERCISED WERE IN "PRNT" MODE . YOU NEED ONLY CONCERN YOURSELF WITH SAVING OR PRINTING YOUR OUTPUT FILES . AS WILL BE DISCUSSED IN SECTION VII.B. IF YOU HAVE ACCESSED ANY FILES FOR UPDATE OR HAVE CREATED A NEW FILE . THE FOLLOWING WILL APPEAR :

```
"YOU HAVE CHANGED YOUR INPUT DATA FILE
IF YOU WISH TO RETAIN YOUR REVISIONS . REMEMBER TO SAVE "
```

TERMINATION OF "MANAGE" FOR ANY WORK DONE IS CUED BY :

```
"THE JOB IS FINISHED
          CP SECONDS EXECUTION TIME"
```

IF THE DATA FILE IS NEW . EXECUTE THE FOLLOWING COMMAND NOW :

```
"/"**SAVE.(FILENAME)**
```

IF YOU HAVE UPDATED A FILE WHICH ALREADY EXISTS . EXECUTE THIS COMMAND :

```
"/"**REPLACE.(FILENAME)**
```

IF YOU NEED TO PRINT FILE "OUT" . OR SAVE A HP PLOTTER FILE . SEE SECTION VII.B.

B) ACCIDENTAL-INTENTIONAL TERMINATION

IF , IN THE ABOVE PROGRAM , YOU ARE ASKED FOR A RESPONSE , AND YOU PRESS "RETURN" WITHOUT HAVING ENTERED ANY INFORMATION , THE PROGRAM IS GOING TO TERMINATE WITH AN INPUT FILE ERROR MESSAGE. IF THIS OCCURS , ANY WORK YOU HAVE DONE WILL BE LOST. YOU MUST START OVER BY REWINDING YOUR FILES WITH THE COMMAND :

```
"/"**RWF**
"RWF FINISHED"
```

THE SECOND LINE INDICATES THAT THE CYBER IS READY FOR YOU TO EXECUTE THE "LOAD AND GO" STATEMENT OF SECTION VII.B. AGAIN.

IF , FOR ANY REASON , YOU NEED TO EXIT THE PROGRAM WHEN YOU ARE NOT ABLE TO ISSUE THE **EXIT** OPTION , SIMPLY PRESS "BREAK". A MESSAGE TO THE EFFECT OF :

```
"**INTERRUPTED**"
```

WILL APPEAR ON THE TERMINAL. PRESS ANY CHARACTER AND THEN "RETURN" TO TERMINATE THE PROGRAM. AS ABOVE , ANY WORK YOU HAVE DONE WILL BE LOST.

NOTE : WHEN YOU ARE ASKED FOR A **YES** OR **NO** ANSWER , A **Y** OR **N** WILL SUFFICE. BE SURE TO ANSWER ALL SUCH PROMPTS WITH ONE OF THESE RESPONSES BECAUSE THE PROGRAM SWITCHES BASED ON YOUR ANSWER.

VII. PROGRAM EXECUTION

A). PREPARATION

THE FILE "MANAGE" IS THE ONLY FILE WHICH YOU MUST HAVE IN ORDER TO USE THIS PROGRAM. IF DATA ALREADY EXISTS , AND IS TO BE UPDATED , IT TOO MUST BE ACCESSED. IF YOU INTEND TO CREATE A FILE FROM TELEMETERED DATA , THIS FILE MUST ALSO BE ACCESSED. THE MOVING OF DATA TO YOUR "WORKING SPACE" IS ACCOMPLISHED WITH THE GET COMMAND.

```
"/"**GET.MANAGE**
```

WILL MOVE THE PROGRAM FILE "MANAGE" INTO YOUR WORK SPACE. A SIMILIAR COMMAND MAY BE EXECUTED TO MOVE ANY OTHER REQUIRED FILES (DATA FILE(S)) INTO THE WORK SPACE.

THE FOLLOWING COMMAND READIES THE PROGRAM FOR USE :

```
"/"**FTN.I=MANAGE.ER.T.L=0.LTP=0**
```

AND WILL BE FOLLOWED SHORTLY BY :

```
"          CP SECONDS COMPILATION TIME
/"
```

YOU ARE NOW READY TO LOAD YOUR DATA AND RUN THE PROGRAM. GO TO SECTION VII.B.

8) LOADING DATA FILES

THE FOLLOWING LISTS THE DEFAULT NAMES OF THE INPUT/OUTPUT FILES :

```
        F1      =      DATA FILE
        F2      =      TELEMETRY DATA FILE
       OUT      =      LINE PRINTER OUTPUT FILE
       011
        :       =      HP PLOTTER OUTPUT FILES
       030
```

THE FILENAME "F2" MUST BE YOUR BONAFIDE FILENAME IF TELEMETERED DATA IS TO BE USED TO CREATE A FILE. THIS FILE IS GENERATED BY RUNNING A SEPARATE PROGRAM NAMED "READATA" . WHICH IS DISCUSSED IN THE APPENDIX (SECTION X)

THE DEFAULT FILENAMES WILL BE USED IN THIS DISCUSSION.

TO START THE PROGRAM WITH NO EXISTING DATA FILE . AND IF YOU INTEND TO SPECIFY THE TIME ARRAY PARAMETERS YOURSELF (MODE = "INIT") . THE FOLLOWING COMMAND WILL START THE PROGRAM :

```
"/"**LGO**
```

THE DATA FILE YOU HAVE CREATED UPON LEAVING THE PROGRAM WILL HAVE THE DEFAULT NAME "F1". IF YOU WISH TO SPECIFY THE FILENAME BEFOREHAND :

```
"/"**LGO.(FILENAME)**
```

WILL START THE PROGRAM . AND THE DATA FILE WILL HAVE THE FILENAME YOU USED WHEN THE PROGRAM IS TERMINATED. THE ABOVE COMMAND IS ALSO USED FOR UPDATING EXISTING FILES. IN THIS CASE . YOUR FILE WILL CONTAIN THE UPDATES WHEN YOU EXIT . AND YOU MAY SAVE THEM BY EXECUTING THE "REPLACE" COMMAND WHICH WAS DISCUSSED EARLIER.

IF YOU INTEND TO CREATE A NEW FILE FROM TELEMETERED DATA . ASSUMING YOUR TELEMETRY DATA FILE IS NAMED "F2" . GIVE THE FOLLOWING COMMAND :

```
"/"**LGO..F2**
```

AS BEFORE . NOT SPECIFYING YOUR DATA FILE NAME WILL DEFAULT IT TO "F1". REMEMBER THAT THERE IS A PRE-DETERMINED ORDER IN WHICH THESE FILES ARE ACCESSED . AND THAT IF YOU WISH TO DEFAULT TO THE PROGRAM NAME OF A FILE . YOU MUST PRESERVE THE NUMBER OF COMMAS AS SHOWN ABOVE. THE TWO CONSECUTIVE COMMAS TELL THE PROGRAM THAT YOU ARE NOT INPUTTING ANY EXISTING DATA FOR "F1" . BUT YOU ARE USING EXISTING DATA FOR "F2". FILES WHICH COME AFTER ANY FILES WITH SPECIFIED NAMES NEED NOT BE CONSIDERED WITH RESPECT TO COMMA PLACEMENT . AS THEY ARE ASSUMED TO BE DEFAULTED.

THE ABOVE COMMAND FOR THE CASE WHERE YOU WANT TO SPECIFY YOUR DATA FILE NAME . WOULD BE AS FOLLOWS :

```
"/"**LGO.F1.F2**
```

IF YOU WANT TO PRINT DATA TO EITHER THE LINE PRINTER OR IN HP PLOTTER FORMATTED FILES . ANY OF THE ABOVE COMMANDS WOULD GENERATE YOUR LINE PRINTER OUTPUT IN FILENAME "OUT" . AND YOUR HP PLOTTER DATA IN FILENAMES "011"."012"....."029"."030" . IT IS NOT ADVISEABLE TO TRY TO PRE-DESIGNATE THE NAMES OF THE HP PLOTTER FILES UNLESS YOU ARE ONLY PRINTING A FEW DATA SETS. IF YOU WISH TO SAVE THESE FILES . USE THE CYBER "RENAME" AND "SAVE" OPTIONS . WHICH WILL BE DISCUSSED LATER.

TO DESIGNATE YOUR LINE PRINTER FILE . EXECUTE THE COMMAND AS :

```
"/"**LGO.F1..(FILENAME)**
```

AGAIN . THE COMMAS MUST BE PRESERVED.

TO RENAME A FILE . THE FOLLOWING COMMAND WILL BE USED AS AN EXAMPLE. THIS EXAMPLE IS FOR A NEWLY CREATED DATA FILE FOR THE MATTIS AVENUE NORTH BASIN . AND AN EVENT FROM NOVEMBER 22.1979 :

```
"/"**RENAME.A11229A=F1**
```

THE RESPONSE WILL BE :

```
"RENAME.A11229A=F1"
```

YOU THEN ISSUE THE "SAVE" COMMAND . DISCUSSED EARLIER.

TO PRINT A FILE . FOR EXAMPLE FILENAME "OUT" . GIVE THIS COMMAND :

```
"/"**PRINT.OUT/EJ/RJE=SWS/NAME=OUT/JOB=(YOUR LAST NAME)**
```

THE CYBER WILL THEN ECHO BACK THE INFORMATION. OUTPUT WILL BE IN BIN NUMBER 21 ON THE EAST WALL OF ROOM 62 . WRB.

IF YOU HAVE APPENDED HP PLOT FILES FOR AN EVENT LONGER THAN FOUR HOURS IN DURATION . USE THE FOLLOWING COMMAND. THE EXAMPLE IS FOR FILE "011" :

```
"/"**PACK.011.**
```

THE CYBER WILL RESPOND :

```
"PACK COMPLETE."
```

YOU MAY NOW RENAME AND/OR SAVE THIS FILE FOR LATER USE.

VIII. SAMPLE DATA FILE FOR PERMANENT STORAGE

THE FOLLOWING PAGE IS AN EXAMPLE OF A PERMANAENT STORAGE DATA FILE. THE FILE NAME IS "A11229A", DENOTING THAT THE DATA STORED IS FOR THE NORTH MATTIS BASIN ("A"), AND THE EVENT DATE IS NOVEMBER ("11") TWENTY-SECOND ("22"), 1979 ("9"), AND THE EVENT IS THE FIRST ("A") OF THE DATE.

YOU WILL NOTICE THAT THE FIRST LINE CONTAINS INTEGER VALUES. THE FIRST VALUE IS THE NUMBER OF ACTUAL DATA RECORDS ("9"), AND THE NEXT 35 VALUES ARE THE EXPONENTS, BASE TEN, OF THE STORED DATA. RECORDS TWO THROUGH TEN CONTAIN THE ACTUAL EVENT DATA FOR THIS FILE. THE FIRST INTEGER IN EACH RECORD REPRESENTS THE TIME, FOLLOWED BY 36 INTEGERS REPRESENTING THE DATA FOR THAT TIME IN THE EVENT. ZEROES REPRESENT EITHER NO AVAILABLE DATA, OR A ZERO VALUE AT THAT TIME. POSITIVE INTEGERS, RAISED TO THE EXPONENT OF THAT COLUMN, REPRESENT THE ACTUAL OBSERVATION AT THAT TIME. NEGATIVE NINES ("-9") INDICATE THAT A TRACE AMMOUNT OF THE CONSTITUENT OCCURRED.

THE COMMENT CARDS HAVE SOME USER-SUPPLIED INFORMATION, SUCH AS RATING CURVE INFO, SITE LOCATION, AND TRACE AMMOUNT INFO, AS WELL AS DEFAULT INFORMATION, SUCH AS WHO CREATED THE FILE AND WHEN, AND WHO INPUT OR UPDATED AN ARRAY AND WHEN.

```
  9  -2  -1    0   0   0    -1  -1  -1  -1  -1  -1  -1   -2    -2   0   0    0  -1  -1   -3   -3    -2    -2  -2  -2  -3  -3  -3  -3
215   2  15  340 308  26   240   0   0   0   0   0   0    0     0   0   0    0   0   0    0    0     0     0   0   0   0   0   0   0
220   2  42    0   0   0     0   1   0   4   0  42   0  110     0  38   0  433  17   0   50    0   710     0  39   0  20   0  -9   0
225   1  51  373 274  11    87   0   0   0   0   0   0    0     0   0   0    0   0   0    0    0     0     0   0   0   0   0   0   0
230   1  44    0   0   0     0  -9   0   3   0  30   0  110     0   6   0  326  19   0   40    0   780     0  25   0  20   0  -9   0
235   1  42  453 144  -9    66   0   0   0   0   0   0    0     0   0   0    0   0   0    0    0     0     0   0   0   0   0   0   0
240   0  35    0   0   0     0   0   0   0   0   0   0    0     0   0   0    0   0   0    0    0     0     0   0   0   0   0   0   0
245   0   0    0   0   0     0  -9   0   3   0  22   0   53     0  16   0  180   8   0   -9    0   390     0  15   0  -9   0  -9   0
250   1  32  152 124  11    58   0   0   0   0   0   0    0     0   0   0    0   0   0    0    0     0     0   0   0   0   0   0   0
255   1  32    0   0   0     0  -9   0   4   0  18   0   44     0  11   0  143   6   0   10    0   270     0  12   0  -9   0  -9   0

11

                                          FILE CREATED 06/25/80 BY DCN
    NORTH MATTIS BASIN , EVENT OF 11/22/79 , FILE=A11229A

    DISCHARGE FROM JAN. 80 RATING CURVE

    TRACE CONCENTRATIONS DESIGNATED BY ALPHA-NUMERICS/-9

    FILES UPDATED :  2  3  4  5  6  7  8 10 12 14 16 18 19 21 23
    25 27 29 31 33 36 37
                                                             DCN    06/25/80
```

IX. SAMPLE LINE PRINTER OUTPUT

THE FOLLOWING PAGE IS AN EXAMPLE OF THE OUTPUT FROM MODE "PRNT". YOU WILL NOTICE THAT WE NOW HAVE EACH OF THE COLUMNAR DATA ARRAYS LABELED AS TO WHAT DATA IS IN THE ARRAY. THE EXPONENTS ARE GIVEN FOR EACH ARRAY AFTER THE DATA IN THIS FORMAT.

INSOFARAS THE DATA ITSELF IS CONCERNED , THE ONLY DIFFERENCE IN THIS PRESENTATION AS OPPOSED TO PRINTING THE ACTUAL DATA FILE IS THAT WE NOW HAVE AN ALPHA-NUMERIC REPRESENTING TRACE AMMOUNTS RATHER THAN A MINUS NINE.

USING THIS TABLE ALSO MAKES THE EXPLANATION OF THE "FILES UPDATED" COMMENT CARDS EASIER. THE NUMBER TWO ("2") ON THIS CARD INDICATES THAT ARRAY NUMBER TWO , OR "RAINFALL" , WAS INPUT OR UPDATED BY USER "DCN" ON JUNE 25,1980.

AS YOU NOTED IN THE DISCUSSION OF THE PRINT OPTION ("PRNT") , THE SECTION OF COMMENTS MAY BE LEFT OFF THIS OUTPUT BY ANSWERING **NO** WHEN ASKED ABOUT THEIR INCLUSION.

```
                                                               P    P
             D    S    D                D       D       D      H   DH      D              D         D          D       D       D       D
        R    I    U    I         C      I       I   KN  IKN    O   IO      I     C        I         I          I       I    C  IC      I
        A    S    S    S    S    H   A  SA   N  SN  JI  SJI    S   SS  O   SO    H        S         S          S       S    H  SH   C  SC
        I    C    PS   SS   U    L   M  SM   I  SI  ET  SET    P   SP  RC  SRC   EOD      S     C   SC         S       S    R  SR   A  SA
        N    H   TEO  TOO   L    O   M  OM   T  OT  LR  OLR    H   OH  GA  OGA   MXE      O     O   OO         O       O    O  OO   D  OD
    T   F    A   ONL  OLL   F    R   O  LO   R  LR  DO  LDO    O   LO  AR  LAR   IYM   L  LL    P   LP     I   LI   Z  LZ   M  LM   M  LM
    I   A    R   TDI  TVI   A    I   N  VN   I  VI  AG  VAG    R   VR  NB  VNB   CGA   E  VE    P   VP     R   VR   I  VI   I  VI   I  VI
    M   L    G   AED  AED   T    D   I  EI   T  ET  HE  EHE    U   EU  IO  EIO   AEN   A  EA    E   EE     O   EO   N  EN   U  EU   U  EU
    E   L    E   LDS  LDS   E    E   A  DA   E  DE  LN  DLN    S   DS  CN  DCN   LND   D  DD    R   DR     N   DN   C  DC   M  DM   M  DM
-----------------------------------------------------------------------------------------------------------------------------------------

  215   2   15   340  308  26  240   0   0   0   0   0    0    0    0   0    0     0   0   0    0    0     0    0   0   0   0   0   0   0
  220   2   42     0    0   0    0   1   0   4   0  42    0  110    0  38    0   433  17   0   50    0   710    0  39   0  20   0   U   0
  225   1   51   373  274  11   87   0   0   0   0   0    0    0    0   0    0     0   0   0    0    0     0    0   0   0   0   0   0   0
  230   1   44     0    0   0    0   G   0   3   0  30    0  110    0   6    0   326  19   0   40    0   780    0  26   0  20   0   U   0
  235   1   42   453  144   E   66   0   0   0   0   0    0    0    0   0    0     0   0   0    0    0     0    0   0   0   0   0   0   0

  240   0   35     0    0   0    0   0   0   0   0   0    0    0    0   0    0     0   0   0    0    0     0    0   0   0   0   0   0   0
  245   0    0     0    0   0    0   G   0   3   0  22    0   53    0  16    0   180   8   0    0    0   390    0  15   0   T   0   U   0
  250   1   32   152  124  11   58   0   0   0   0   0    0    0    0   0    0     0   0   0    0    0     0    0   0   0   0   0   0   0
  255   1   32     0    0   0    0   G   0   4   0  18    0   44    0  11    0   143   6   0   10    0   270    0  12   0   T   0   U   0

EXP=   -2   -1     0    0   0   -1  -1  -1  -1  -1  -1   -1   -2   -2   0    0     0  -1  -1   -3   -3    -2   -2  -2  -2  -3  -3  -3  -3

 11 COMMENT RECORDS EXIST

*****    COMMENTS    *****

                                                     FILE CREATED 06/25/80 BY DCN
       NORTH MATTIS BASIN . EVENT OF 11/22/79 . FILE=A11229A

       DISCHARGE FROM JAN. 80 RATING CURVE

       TRACE CONCENTRATIONS DESIGNATED BY ALPHA-NUMERICS/-9

       FILES UPDATED :   2   3   4   5   6   7   8  10  12  14  16  18  19  21  23
       25 27 29 31 33 36 37
                                                                DCN     06/25/80
```

X. APPENDIX : PROGRAM "READATA"

THE TELEMTRY SYSTEM FOR THIS PROJECT PRODUCES TWO FILES ON THE PROJECT ACCOUNT : "TOC" AND "RAWDAT". RAWDAT IS A DIRECT ACCESS FILE AND MUST BE MOVED TO YOUR WORKSPACE BY THE FOLLOWING COMMAND :

```
"/"**ATTACH.RAWDAT**
```

READATA AND TOC MAY BE ACCESSED VIA THE "GET" COMMAND DISCUSSED PREVIOUSLY. RAWDAT CONTAINS THE MINUTE BY MINUTE DATA FED BACK TO THE OFFICE FROM THE FIELD SITES. IT CONTAINS ONLY DATA. TOC IS THE "TABLE OF CONTENTS" FOR RAWDAT. IT CONTAINS ONE RECORD FOR EACH EVENT. THE EVENT RECORD TELLS THE DATE AND TIME OF THE ONSET OF THE EVENT. AND THE NUMBER OF ONE-MINUTE RECORDS RAWDAT CONTAINS FOR THAT EVENT. IN ORDER TO USE "READATA" TO GENERATE THE INPUT FILE FOR "MANAGE". YOU MUST DECIDE WHICH EVENT FROM TOC YOU WANT TO WORK ON. AND DETERMINE THE RECORD NUMBER IN TOC OF THAT EVENT. THE FOLLOWING SERIES OF COMMANDS LEADS TO THE ONLY USER RESPONSE OF THE PROGRAM :

```
"/"**FTN.I=READATA.ER.T.L=0.LTP=0**
" 0.355 CP SECONDS COMPILATION TIME
 /"**LGO.TOC,RAWDAT**
"ENTER NUMBER OF TOC FILES TO SKIP. NUMBER TO READ
?"**     **
```

YOUR RESPONSE WOULD BE **XX.1** . WHERE XX IS THE RECORD NUMBER OF THE EVENT YOU WANT TO WORK ON. MINUS ONE. THE INTEGER ONE IN YOUR RESPONSE INDICATES ONLY ONE EVENT IS TO BE PROCESSED. THE PROGRAM WILL SIGNAL COMPLETION WITH :

```
" 0.133 CP SECONDS EXECUTION TIME
/"
```

THERE ARE SIX FILES GENERATED BY THE PROGRAM :

01 - CONTAINS EVENT CHECK DATA FOR NORTH MATTIS
02 - CONTAINS EVENT CHECK DATA FOR SOUTH MATTIS
03 - CONTAINS EVENT CHECK DATA FOR JAMES AND DANIEL
04 - CONTAINS EVENT CHECK DATA FOR SOUTH JOHN
05 - CONTAINS EVENT CHECK DATA FOR NORTH JOHN
07 - CONTAINS INPUT DATA FOR MANAGE

FILE "07" IS REFERRED .O AS FILE "F2" IN THE PREVIOUS DISCUSSION AS TO LOADING THE INPUT DATA FILES FOR A "MANAGE" RUN. THE FILE "07" IS READY TO USE AS TELEMETERED DATA INPUT. IT HAS SIXTEEN DATA ITEMS PER RECORD. AND ONE RECORD FOR EACH MINUTE OF THE SPECIFIED EVENT. THESE ITEMS ARE THE TIME (MILITARY). THREE RAINFALL RECORDS (SITES 2. 3. AND 4). SEVEN BUBBLER READINGS (ONE EACH FOR THE MATTIS AND MICRO-BASINS. TWO EACH FOR THE JOHN BASINS). AND FIVE ZERO/ONE VALUES THAT INDICATE TO "MANAGE" WHETHER OR NOT A SAMPLE WAS TAKEN AT THAT SITE IN THE PAST MINUTE.